Chapter 3

Design of Sustainable Public Buildings

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3.1. BUILDING DESIGN BY BIM

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BIM is an acronym for Building Information Modeling, a certain method of working and collaborating digitally in a building project. The word 'model' refers to the fact that designing with BIM is always 3D modelling. Using BIM methods in a building project requires using digital object-oriented parametric tools that support BIM. Autodesk Revit® (2020) is one such parametric BIM-supporting tool among many advanced CAD-programmes. For ease of reference, all instructions in this book will refer to Revit.

3.1.1. Industrialised Building, Modular Design and Transport

One of the main advantages of building with timber elements is that it is possible to complete the building carcass relatively fast. While mass timber structures are often built as components off site and assembled at the project site, light frame construction typically occurs entirely on site. Increasingly, however, elements of light frame buildings are fabricated off site and assembled on the job. Off-site construction offers greater control over construction conditions and improved safety oversight for all material types while requiring less skilled labour on site and contributing to faster construction timelines. If we want to build public buildings fast, economical and safe, we need to apply a modular design. An industrialised building system (IBS) may be defined as one in which all building components such as walls, floor slabs, beams, columns and staircases are mass produced either in factory or off site under strict quality control and minimal on-site activities (Thanoon et al., 2013; Trikha, 1999). The objectives of modular co-ordination are to create the basis upon which the variety of types and sizes of building components can be minimized, and secure that all elements fit together without cutting or extending even when different suppliers manufacture the components and fittings.

The modular system using 100 mm as a basic module 'M', has been made international in order to facilitate trade in building materials, etc. (Thanoon et al., 2013). The unit is sufficiently small to satisfy most requirements regarding intervals on normal building components. The basic module may also be a unit which is 'too small' to achieve the desired simplification and limitations of variants. This applies particularly to large building components, such as floor and wall elements in the structural framework, and the so-called planning modules have therefore been introduced for use in the planning modules which are multiples of the basic module. Planning modules are mainly used in the design of the carcass, i.e. all structural and shielding parts of the building are planned by means of these dimensions, while the basic module is used in the design of the interior (Fig. 3.1).

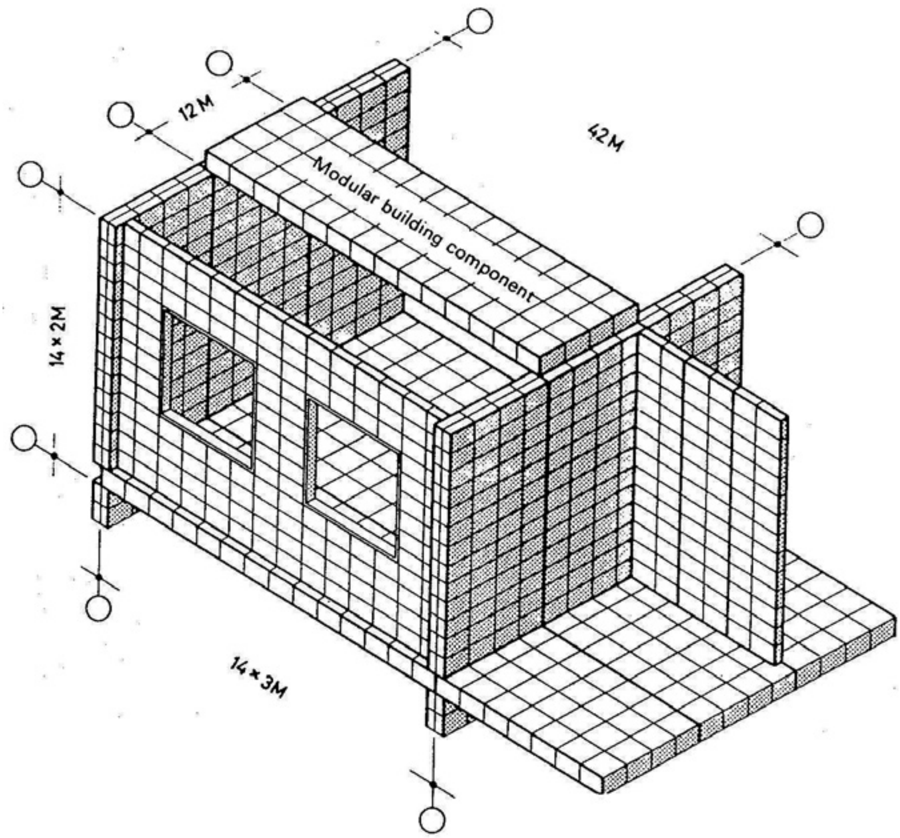

Fig. 3.1. All building components in this model are correctly located in their modular zones within the modular space grid. However, technical detailing of the connections usually leads to the grid being broken in several places (Nissen, 1972).

Planning module 3M or 6M is the common horizontal dimension used in most European countries, including Scandinavia. Within the ISO, many countries use 2M or 3M for the vertical planning module.

In order to use the maximum possible number of uniform types of components in dwelling houses and other types of building, these works should be designed on the basis of planning modules, which are multiples of 3M unless heavy functional considerations call for other dimensions. The establishment of larger planning modules, for use in industrial and public buildings, can make use of 'Industriebaumass' (Neufert, 2018) IBA = 2500 mm or IBA/2 = 1250 mm, or other preferred multimodules, e.g. 12M horizontal and 6M vertical.

The choice of preferred multimodules is not, of course, just a question of production methods and money. Preferred multimodules have a direct influence on room dimensions, spans, etc., and they must therefore be determined on the basis of the functional requirements of the project.

As an example of preferred multimodules taken from practice, we can look at modular concrete floor slabs, which use controlling dimensions of 12, 18 or 24M (cross-section) and lengths ranging from 18M to 54M. Vertical dimensions for normal storeys of apartment houses controlled by the planning module 2M have a fixed storey height of 28M. The floor slab, which is the structural part of the horizontal division, is placed one joint proportion (5 mm) under the modular plane (Fig. 3.1).

In general, preferred multimodules must be selected to suit the function, construction and material of the components with a view to achieving an economical production. Solid wood panels are considerably lighter than concrete elements, so we will be able to design larger components without taking into consideration the lifting capability of lorries or cranes. Bear in mind that the limits of transportation, rather than physical handling of the component, often will define the maximum size of the component. It is not uncommon that timber elements are produced quite far away, maybe even in another country.

In Denmark, a special transport permit must be issued if the total dimensions of freight transport by lorry exceed a width of 3.30 m, a height of 4.10 m and a length of 22.0 m. Total height is here typically limited by freeway bridges. According to European best practice guidelines for abnormal road transports and Directive 96/53/EC, no permit is needed for road transport with a maximum overall height of 4 metres (European Parliament & Council of the European Union, 2008). The objective of these best practice guidelines is to contribute to the development of European environment in which cross-border abnormal road transports can take place with a minimum of hassle, ideally in an uninterrupted way.

3.1.2. Modular Grid, Tolerances and Placing of Components

Once the module, the planning module and the preferred multimodule have been decided, and possibly standardised, two further roads are open for development of the modular system:

A. Design over a modular grid.

B. Design with modular components.

In case A, the project is drafted over a modular grid, and both principal and detail dimensions are fitted to the grid. This approach would be fine if our main structural elements are joists and beams made of engineered timber, which replace steel in many building projects. In case B, the individual components are first defined, e.g. whole wall timber elements or box modules, and later the modular grid is designed to accommodate these modular components.

The area between modular lines is called the modular zone. A modular component must normally be kept within its modular grid, but technical considerations may require certain connections which might entail the components exceeding their modular zones, e.g. tongue and groove, bolted connections and similar. When we have simple, uniform, modular components in a row, there is no conflict with modular grid, and we can design both with a grid and with modular components. However, as soon as we have to design other connections, e.g. corners or T-junctions, problems arise in which either the grid must give way or special, frequently non-modular, components must be made (Nissen, 1972).

The planning module grid is used mainly for the design of the carcass, though it also serves as a way of navigating the project, setting out, and controlling the mounting process. During the design work, the building components are placed in relation to each other using the planning module grid as means of coordination.

Structural exterior walls are normally placed in the modular grid with their edges along the modular lines.

Structural interior walls are placed with their centre planes along the modular line, unless the technical considerations call for a different placing.

Floor components are placed within their modular zones.

Separated modular grids may occur as a result of special technical conditions.

For accomplishing the requirement of modular coordination, all components need to be standardised for production. Such standardisation of space and elements needs prescribing tolerances at different construction stages such as manufactured tolerances, setting out tolerances and erection tolerances, so that the combined tolerance obtained on statistical considerations is within the permitted limits (Trikha, 1999). Wall elements in a row will be separated with joints where they are divided with a grid line. If the modular grid is the horizontal controlling dimension, e.g. 24M, then the wall elements will have a basic dimension of 24M – 2 x (½ joints). The joint dimension here is governed by the sum of manufactured tolerances $f_{max} - f_{min}$, erection tolerances $T_{max} - T_{min}$ and the joint (total) between elements for climate tolerances. Wall elements that do not comply with modular dimensions, and in terms of size are not within the agreed tolerances, must be rejected.

Timber elements, e.g. CLT panels are cut to size, including door and window openings, with state-of-the art computer numerical controlled (CNC) routers, capable of making complex cuts with low tolerances. Normal tolerance is down to ±3 mm, but you also have to consider deformation due to climate change like relative air humidity and temperature. Especially if the finished surfaces of the panels are visible and not covered with fire protection plasterboard.

3.1.3. Collaborate with Discipline Models, Project Parameters

Every 3D modelling BIM-software has the ability to insert grid lines in a plan view (the grid does not belong to a particular view) and levels for vertical control, and the opportunity to customize grid heads. The modular grid can be placed manually or with an offset. We add Aligned Dimensions afterwards in, e.g. Revit. Lock (Pin) the grid to avoid any unwanted editing (Fig. 3.2).

When the modular planning grid is all set up, we just draw corresponding architectural wall type components as continued (chain) walls and put in the openings for doors and windows and so forth. That is essentially all the architect will do at this point. Depending on what system we are using for tender, it is now up to the structural engineer, or the manufacturer, to divide the walls into the individual wall elements.

First, we start up a new project file and then we Link the architect's 3D building model to our project, so we are able to use the architect's walls and modular grid as an underlying drawing. We might want to link the structural engineer's model as well. In Revit, this is also the advantage that we can see if the architect or engineer has moved any walls, openings or even gridlines, when we periodically update the linked model. At this point, it is clearly a bad idea to alter the grid at all, unless the structural engineer or the manufacturer are demanding a change. Now we could just copy the design by manually drawing the exact same components in our timber element project and use a split with gab tool to divide the walls. However, in Revit there is a smarter way of doing this to minimize the risk of an input error from our team. A Collaborate function monitors and coordinates changes to elements between our host project and linked model. When other teams move or change a monitored element, our team is notified so that we can adapt their designs or resolve issues. At this point, use the Copy/Monitor tool to transfer the modular grid only.

In Revit the individual walls are transferred in a different way, and an advantage of this method is that the walls geometry is automatically updated

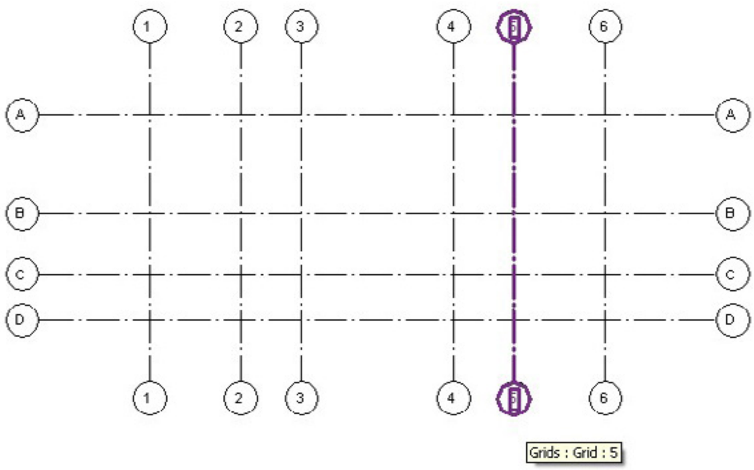

Fig. 3.2. Basic grids in Revit.

when we reload the linked models. We use Create Parts from the Modify menu to get geometry of relevant walls. In the case of generic elements, a single part element is created. For other elements with layers or subcomponents, such as walls, individual parts will be created. The geometry is automatically updated to reflect any changes to the element from which they are derived. Modifying a part has no effect on the original element. Note that the project parameters and shared parameters and level data propagate to parts.

Parts Visibility specifies whether parts and the elements they were created from will display in a particular view. In a floor plan view, choose Show Parts in view properties. We can now start dividing our walls into individual solid wood panels. Again, Revit has a handy tool that will speed up the process. With Divide Parts, we can sketch geometry to divide the parts, or we can divide them with one or more intersecting references, such as levels or grids. We can handle non-modular wall elements by unselecting the dividing reference (gridline) or manually divide or merge the remaining non-modular parts. In the Divisions Geometry Properties panel, we specify the amount of gab we want between all our individual elements, or just set an Offset when you select the grids. Gab or joint dimensions can be specified by the manufacturer, assessed in relation to special technical conditions, and reduced or extended demands to tolerances.

Although wood panel products are often made from gluing layers of solid-sawn lumber together, they are represented as one solid in our 3D model. Still there are some advantages in Revit when we define individual wall parts as an Assembly. The Assemblies category of Revit elements supports construction workflows by letting you identify, classify, quantify, and document unique element combinations in the model. Each unique assembly is listed as a type in the Project Browser. We can select an assembly type in the Project Browser or an instance of that type in the drawing area and generate one or more types of isolated views of the assembly as well as parts lists, material take-offs, and sheets. Assembly views are listed in the Project Browser, from where they can be easily dragged onto the project or assembly sheet views as needed. For now, we only make use of the Assemblies ability to keep track of how many types of panels we are generating. Use the Assembly Name 'TYPE' and all following creations are automatically named the same followed by a type number identifier. Depending on the specific project, we might want to create one code for exterior walls and another for partition walls and floors and so forth.

We need to organize all the different assemblies / elements we created by adding more parameters and show this information in Tags. There is a difference between instance and type parameter. Instance Parameters enables us to modify the parameter value separately for every instance or element. Type Parameters will modify the parameter value, which applies to all elements of the same family type. In Revit we can annotate each wall part with Tag by Category. By default, Tags will display the Assembly Name and Mark parameter (if not empty). In Properties for the selected assembly, we could add a part number in the Identity Data / Mark wall-part, space, eight (WP_8) assuming there are eight instances of the type. However, it is better to edit the Tag so it displays the prefix 'WP_' so we only put 8 in the Properties field. Continue to add Instance Parameters and unique identifiers for duplicates to all parts / assemblies.

3.1.4. Number Plan with Element List, Production Drawings

If we were the manufacturer of solid wood panels, it would also be handy to display some information about logistics, like production or delivery batch number / dates or truck number. A maximum of 40 m³ or 20 t of CLT panels can be transported horizontally per truckload, depending on the articulated lorry (Stora Enso, 2012).

In all BIM-software we are able to add a user-defined field for Project Parameters. Note that in Revit we have to use Shared Parameter if we want to display the data in both schedules and tags. These user-defined fields are stored separately in a Shared Parameter File (.txt), which can be reused in other projects. In the txt-file we can add a new Group called 'Logistics' and define a field named 'Truck Number' (Fig. 3.3). Hereafter, we are able to add our field to Project Properties. We organize it under Identity Data and set it to be an Instance for individual elements and specify that the field will appear in the category for Assemblies only. Now we can edit our wall assemblies' tags to display the Shared Parameter Truck Number below

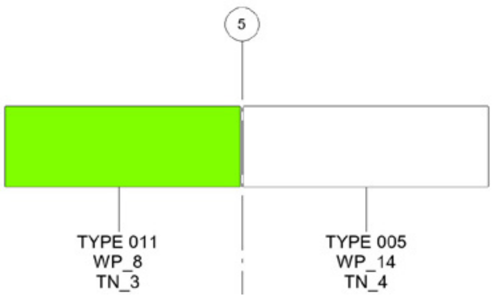

Fig. 3.3. Example of Tag with a panel type and wall part identifier and truck number.

our optional Mark wall part identifier and add this information to all of our elements. Again, edit the assembly tag to display the 'TN_' as a prefix with a line break. Note that we can also use tags on the elevation views of assemblies we generate to show dimensions of recess / rebates and holes.

To enhance the visual display of information further, we can add some filters to the view that represents our floor plan drawing. Visibility / Graphics overrides can specify whether elements and categories are visible in the view and their graphical appearance (colour, lineweight, and linestyle). What we want to do is define a new Rule-based Filter and name it 'TN_3'. This filter should apply to the Parts Categories, and the Filter Rule trigger is the Shared Parameter Truck Number; equals; 3. Now we can add the 'TN_3' Filter to our floor plan view, set the Cut Pattern Override to Solid fill, and change the colour to, e.g. green. Hereafter, we just duplicate the Filter we just created and make appropriate adjustments like changing the colour.

If we want to make a Number plan with element list, we still need to add some Schedules to our drawing. In Revit we create a Part Schedule and select the relevant fields with detailed information from the Parts Category (Assembly Name <type>; Count <total of each type>; Height; Thickness; Length; Area; Weight <calculated parameter>). It is even possible to retrieve the original Type and Category from the linked file. We also need logistic information form an Assembly Schedule (Type <combined with> Mark; Count; Truck Number). Schedules are filtered and formatted much in the same way as MS Excel (Fig. 3.4).

We only need to drag our floor plan view and the schedules on to a sheet and we have finished the Number plan with element list. We can continue to work smarter and add more Type parameters like 'cost' for estimation of bid price or tender cost of production. Because it is BIM, all data on sheets (drawings) are updated automatically if we make any project alterations.

Assembly Schedule			
Type/Part Mark/	Count	Mark	Truck Number
TYPE 011 / Part 8	1	8	3
TYPE 002	1		5
TYPE 007 / Part 1	1	1	5
TYPE 007 / Part 2	1	2	7

Fig. 3.4. Example of schedule with logistic information. Column 1 consists of merged data, making the 'Mark' column redundant.

3.1.5. Planning for Mounting, Operational Drawings

The previous described techniques can also be used to create the Planning for mounting. The key logistic information regarding the mounting are panel dimensions and positioning according to grids and precise timing of the mounting process. We can reuse the overall layout from the Number plan but change graphics overrides to display the same colour for all elements, which are to be mounted on day 1, and another colour for day 2 and so forth. We need to create a schedule with precise information for each of the working days. The schedule must display the amount and type of panels that arrive, the truck number, and the arrival time. Create a filter to match the background colour of schedules with the colour of corresponding wood panels.

The wall elements must be transferred using the lifting gear provided on site or by the contractor. Care must be taken to ensure that the crane system is adequately stable during the construction phase. Although the solid wood panels are not that heavy, CLT weighs approx. 470 kg/m^3, they are quite sensitive to strong winds. The geometry and shape of the load play a great role in what is known as the 'sail area' effect. If we are lifting a large flat sheet, it can catch the wind like a sail. This can cause the load to be pushed out of plum resulting in adverse effects on the crane. When lifting in wind, the rule of thumb for manageable sail effect is 1 m^2 = 1 tonnes. Therefore, the area and weight of the wood panel need to be listed in such a way that the crane operator easily can calculate the maximum wind speed allowed during lifting operations that would result in the piece staying plum on the crane.

We hope that we have pointed out the key principles and performance benefits of designing wooden public buildings in a modular system. We hope we have demonstrated how to use basic BIM and parameters to work smarter. We showed ways to collaborate with discipline models and ways to monitor and coordinate changes to elements between our host projects. We pointed out the differences between Type, Instance, Project, (user defined) Shared Parameters. We showed how to create schedules that can reflect parameters. We demonstrated that it is possible to use parameters to apply filters and graphical overrides to components and schedules. We described the applications of Number plan with element list, and Planning for mounting. We transmitted knowledge about restrictions regarding transport and lifting of mass timber structures.

The key word examples for some of the conditions, which should be reflected in the schedules are:

- type and part identifiers;
- basic dimensions of relevance;
- truck number, information regarding delivery process;
- area (sail) vs. weight information for lifting;
- mounting sequence of elements.

3.2. LOAD BEARING STRUCTURES

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3.2.1. General Data

In most European countries European design codes are being used for the structural design of load bearing structures. Eurocode 5 is used for the structural design of timber structures. Further in this chapter the main principles of structural timber design will be presented.

Timber as a material is sensitive to relative humidity of the surrounding air. These conditions are evaluated by assigning structures to the service classes. The service class system is mainly aimed at assigning strength values and for calculating deformations under defined environmental conditions.

There are 3 service classes according to EN 1995-1-1:

- *Service class 1* is characterized by a moisture content in the materials corresponding to a temperature of 20 °C and the relative humidity of the surrounding air only exceeding 65 % for a few weeks per year. In Service class 1 the average moisture content in most softwood will not exceed 12 %.
- *Service class 2* is characterized by a moisture content in the materials corresponding to a temperature of 20 °C and the relative humidity of the surrounding air only exceeding 85 % for a few weeks per year. In Service class 1 the average moisture content in most softwood will not exceed 20 %.
- *Service class 3* is characterized by climatic conditions leading to higher moisture contents than in Service class 2.

The design value of strength property is calculated according to Equation 3.1:

$$f_\mathrm{d} = k_\mathrm{mod}\frac{f_\mathrm{k}}{\gamma_\mathrm{M}}, \tag{3.1}$$

where f_k is the characteristic value of a strength property, which is determined according to EN standards for the relevant material; γ_M is the partial factor for a material property according to Table 3.1; and k_{mod} is a modification factor, taking into account the effect of the duration of load and moisture content, according to Table 3.2.

The recommended values of partial safety factors for timber-based products, for material properties and resistances according to EN 1995-1-1 are provided in Table 3.1.

Table 3.1

Partial Factors for Material Properties and Resistances According to EN 1995-1-1

Fundamental combinations:	γ_M
Solid timber	1.3
Glued laminated timber Glulam	1.25
LVL, plywood, OSB	1.2
Particleboards	1.3
Fibreboards, hard	1.3
Fibreboards, medium	1.3
Fibreboards, MDF	1.3
Fibreboards, soft	1.3
Connections	1.3
Punched metal plate fasteners	1.25
Accidental combinations	1.0

Some of the main modification factors of timber-based products, taking into account the effect of the duration of load and moisture content, according to EN 1995-1-1 are provided in Table 3.2. The examples of assignment of structures to the service classes are provided in National Annexes of each country. The effect of member size on tension or bending strength may be taken into account by height coefficient k_h.

For rectangular solid timber with a characteristic timber density less or equal to 700 kg/m^3, the reference depth in bending or width (maximum cross-sectional dimension) in tension is 150 mm. For depths in bending or widths in tension of solid timber less than 150 mm the characteristic values for $f_{m,k}$ and $f_{t,0,k}$ may be increased by factor k_h according to EN 1995-1-1 (Equation 3.2):

$$k_h = \min \begin{cases} \left(\dfrac{150}{h}\right)^{0.2}, \\ 1.3 \end{cases} \tag{3.2}$$

where h is the depth for bending members or width for tension members, in mm.

For rectangular glued laminated timber, the reference depth in bending or width in tension is 600 mm. For depths in bending or widths in tension of glued laminated timber less than 600 mm the characteristic values for $f_{m,k}$ and $f_{t,0,k}$ may be increased by factor k_h according to EN 1995-1-1 (Equation 3.3):

$$k_h = \min\begin{cases}\left(\dfrac{600}{h}\right)^{0.1}, \\ 1.1\end{cases} \tag{3.3}$$

Table 3.2

Modification Coefficient Values of Main Timber-based Products According to Eurocode 5 (EN 1995-1-1:2004 + AC:2006 + A1:2008)

Solid timber	Standard	Service class	Load-duration class				
			Permanent action	Long term action	Medium term action	Short term action	Instantaneous action
Solid timber	EN 14081-1:2016+A1:2019	1	0.60	0.70	0.80	0.90	1.10
		2	0.60	0.70	0.80	0.90	1.10
		3	0.50	0.55	0.65	0.70	0.90
Glued laminated timber	EN 14080:2013	1	0.60	0.70	0.80	0.90	1.10
		2	0.60	0.70	0.80	0.90	1.10
		3	0.50	0.55	0.65	0.70	0.90
LVL	EN 14374:2004 EN 14279:2004+A1:2009	1	0.60	0.70	0.80	0.90	1.10
		2	0.60	0.70	0.80	0.90	1.10
		3	0.50	0.55	0.65	0.70	0.90
Plywood	EN 636:2012+A1:2015	1	0.60	0.70	0.80	0.90	1.10
		2	0.60	0.70	0.80	0.90	1.10
		3	0.50	0.55	0.65	0.70	0.90
OSB	EN 300:2006						
	OSB/2	1	0.30	0.45	0.65	0.85	1.10
	OSB/3, OSB/4	1	0.40	0.50	0.70	0.90	1.10
	OSB/3, OSB/4	2	0.30	0.40	0.55	0.70	0.90

3.2.2. Ultimate Limit States

Elements subjected to the tension force parallel to the grain should satisfy the following condition according to EN 1995-1-1:

$$\sigma_{t,0,d} \leq f_{t,0,d}, \tag{3.4}$$

where $\sigma_{t,0,d}$ is the design tensile stress along the grain; and $f_{t,0,d}$ is the design tensile strength along the grain.

Elements subjected to the compression force parallel to the grain should satisfy the following condition according to EN 1995-1-1:

$$\sigma_{c,0,d} \leq f_{c,0,d}, \tag{3.5}$$

where $\sigma_{c,0,d}$ is the design compressive stress along the grain; and $f_{c,0,d}$ is the design compressive strength along the grain.

Further in the chapter stability calculations are provided.

Elements subjected to the compression force perpendicular to the grain should satisfy the following condition according to EN 1995-1-1:

$$\sigma_{c,90,d} \leq k_{c,90} \cdot f_{c,90,d}, \tag{3.6}$$

$$\sigma_{c,90,d} = \frac{F_{c,90,d}}{A_{ef}}, \tag{3.7}$$

where $\sigma_{c,90,d}$ is the design compressive stress in the effective contact area perpendicular to the grain; $F_{c,90,d}$ is the design compressive load perpendicular to the grain; A_{ef} is the effective contact area in compression perpendicular to the grain; $f_{c,90,d}$ is the design compressive strength perpendicular to the grain; and $k_{c,90}$ is a factor taking into account the load configuration, the possibility of splitting and the degree of compressive deformation.

The effective contact area perpendicular to grain A_{ef} should be determined taking into account an effective contact length perpendicular to the grain, where the actual contact length at each side is increased by 30 mm, but not more than a, l or $l_1/2$, as shown in Fig. 3.5.

The value of $k_{c,90}$ may increase the compressive strength perpendicular to the grain, which evaluates the stress redistribution in the higher area than the actual. The limiting value of $k_{c,90}$ is equal to 1.75.

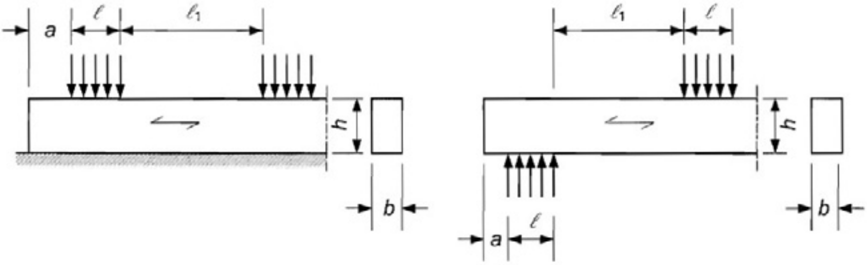

Fig. 3.5. Application of loading perpendicular to the grain (EN 1995-1-1).

For members on continuous supports, provided that $l_1 \geq 2h$, see Fig. 3.5 (left), the value of $k_{c,90}$ should be taken equal to:

- 1.25 for solid softwood timber;
- 1.50 for glued laminated softwood timber.

For members on discrete supports, provided that $l_1 \geq 2h$, see Fig. 3.5 (right), the value of $k_{c,90}$ should be taken equal to:

- 1.50 for solid softwood timber;
- 1.75 for glued laminated softwood timber provided that $l \leq 400$ mm,

where h is the depth of the member and l is the contact length.

Elements subjected to bending should satisfy the following conditions according to EN 1995-1-1:

$$\frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} \leq 1{,}0, \tag{3.8}$$

$$k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} \leq 1{,}0, \tag{3.9}$$

where $\sigma_{m,y,d}$ and $\sigma_{m,z,d}$ are the design bending stresses about the principal axes; $f_{m,y,d}$ and $f_{m,z,d}$ are the corresponding design bending strengths.

Factor k_m evaluates the stress re-distribution, which depends on the shape of cross section. For solid timber, glued laminated timber and LVL it is:

- for rectangular cross-sections equal to 0.7;
- for other cross-sections equal to 1.0.

For elements subjected to shear with a stress component parallel to the grain, Fig. 3.6 (left), also for shear with both stress components perpendicular to the grain, Fig. 3.6 (right), the following expression should be satisfied according to EN 1995-1-1:

$$\tau_d \le f_{v,d}, \tag{3.10}$$

where τ_d is the design shear stress; and $f_{v,d}$ is the design shear strength for the actual condition.

For verification of shear resistance of members in bending, the influence of cracks should be taken into account using an effective width of the member according to EN 1995-1-1:

$$b_{ef} \le k_{cr} b, \tag{3.11}$$

where b is the width of the relevant section of the member.

The recommended value for k_{cr} according to EN 1995-1-1 is:

- 0.67 for solid timber and glued laminated timber;
- 1.0 for other wood-based products in accordance with EN 13986 (EN 13986:2004 +A1:2015) and EN 14374 (EN 14374:2004).

Elements subjected to compression stresses at an angle to the grain should satisfy the following condition according to EN1995-1-1 (see Fig. 3.7):

$$\sigma_{c,\alpha,d} \le \frac{f_{c,0,d}}{\frac{f_{c,0,d}}{k_{c,90} f_{c,90,d}} \sin^2\alpha + \cos^2\alpha}, \tag{3.12}$$

where $\sigma_{c,\alpha,d}$ is the compressive stress at an angle α to the grain; and $k_{c,90}$ is a factor taking into account the load configuration, the possibility of splitting and the degree of compressive deformation.

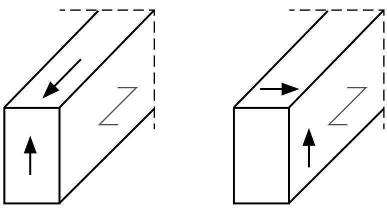

Fig. 3.6. Member with a shear stress component parallel to the grain (left) and member with both stress components perpendicular to the grain (right) (EN 1995-1-1).

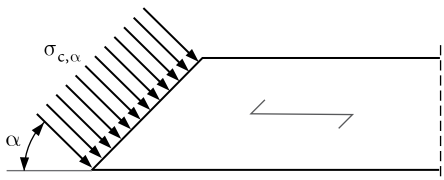

Fig. 3.7. Compressive stresses at an angle to the grain (EN 1995-1-1).

Elements subjected to the combined bending and axial tension parallel to the grain shall satisfy the following condition according to EN 1995-1-1:

$$\frac{\sigma_{t,0,d}}{f_{t,0,d}}+\frac{\sigma_{m,y,d}}{f_{m,y,d}}+k_m\frac{\sigma_{m,z,d}}{f_{m,z,d}}\le 1.0, \tag{3.13}$$

$$\frac{\sigma_{t,0,d}}{f_{t,0,d}}+k_m\frac{\sigma_{m,y,d}}{f_{m,y,d}}+\frac{\sigma_{m,z,d}}{f_{m,z,d}}\le 1.0. \tag{3.14}$$

Elements subjected to the combined bending and axial compression parallel to the grain shall satisfy the following condition according to EN 1995-1-1:

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2+\frac{\sigma_{m,y,d}}{f_{m,y,d}}+k_m\frac{\sigma_{m,z,d}}{f_{m,z,d}}\le 1.0, \tag{3.15}$$

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2+k_m\frac{\sigma_{m,y,d}}{f_{m,y,d}}+\frac{\sigma_{m,z,d}}{f_{m,z,d}}\le 1.0. \tag{3.16}$$

Further in this chapter the stability calculations of column and beam type elements are provided.

Columns subjected to either compression or combined compression and bending should satisfy the stability condition according to EN 1995-1-1:

$$\frac{\sigma_{c,0,d}}{k_{c,y}f_{c,0,d}}+\frac{\sigma_{m,y,d}}{f_{m,y,d}}+k_m\frac{\sigma_{m,z,d}}{f_{m,z,d}}\le 1.0, \tag{3.17}$$

$$\frac{\sigma_{c,0,d}}{k_{c,y}f_{c,0,d}}+\frac{\sigma_{m,y,d}}{f_{m,y,d}}+k_m\frac{\sigma_{m,z,d}}{f_{m,z,d}}\le 1.0, \tag{3.18}$$

where the relative slenderness rations should be determined as

$$\lambda_{rel,y}=\frac{\lambda_y}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0.05}}}, \tag{3.19}$$

$$\lambda_{rel,z}=\frac{\lambda_z}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0.05}}}, \tag{3.20}$$

where λ_y and $\lambda_{rel,y}$ are slenderness ratios corresponding to bending about the y-axis (deflection in z-direction); λ_z and $\lambda_{rel,z}$ are slenderness ratios corresponding to bending about the z-axis (deflection in y-direction); and $E_{0.05}$ is the fifth percentile value of the modulus of elasticity parallel to the grain.

$$k_{c,y}=\frac{1}{k_y+\sqrt{k_y^2-\lambda_{rel,y}^2}}, \tag{3.21}$$

$$k_{c,z} = \frac{1}{k_z + \sqrt{k_z^2 - \lambda_{rel,z}^2}}, \tag{3.22}$$

$$k_y = 0.5\left(1 + \beta_c\left(\lambda_{rel,y} - 0.3\right) + \lambda_{rel,y}^2\right), \tag{3.23}$$

$$k_z = 0.5\left(1 + \beta_c\left(\lambda_{rel,z} - 0.3\right) + \lambda_{rel,z}^2\right), \tag{3.24}$$

where β_c is a factor for members with the straightness limits defined in EN 1995-1-1; and β_c is equal to 0.2 for solid timber and equal to 0.1 for glued laminated timber and LVL.

The beams subjected to either bending or combined bending and compression should satisfy the following stability conditions. In the case where a combination of moment M_y about the strong axis y and compressive force N_c exists, the stresses should satisfy the following condition according to EN 1995-1-1:

$$\left(\frac{\sigma_{m,d}}{k_{crit} f_{m,d}}\right)^2 + \frac{\sigma_{c,0,d}}{k_{c,z} f_{c,0,d}} \leq 1.0, \tag{3.25}$$

where $\sigma_{m,d}$ is the design bending stress; $\sigma_{c,0,d}$ is the design compressive stress parallel to the grain; $f_{c,0,d}$ is the design compressive strength parallel to the grain; and $k_{c,z}$ is determined according to Equation 3.22.

The relative slenderness for bending should be determined according to EN 1995-1-1:

$$\lambda_{rel,m} = \sqrt{\frac{f_{m,k}}{\sigma_{m,crit}}}, \tag{3.26}$$

where the critical bending stress is determined according to EN 1995-1-1:

$$\sigma_{m,crit} = \frac{M_{y,crit}}{W_y} = \frac{\pi\sqrt{E_{0.05} I_z G_{0.05} I_{tor}}}{l_{ef} W_y}, \tag{3.27}$$

where $E_{0.05}$ is the fifth percentile value of modulus of elasticity parallel to the grain; $G_{0.05}$ is the fifth percentile value of shear modulus parallel to the grain; I_z is the second moment of area about the weak axis z; I_{tor} is the torsional moment of inertia; l_{el} is the effective length of the beam, depending on the support conditions and the load configuration, according to Table 3.3; W_y is the section modulus about the strong axis y.

For softwood with solid rectangular cross-section, $\sigma_{m,crit}$ should be determined according to EN 1995-1-1:

$$\sigma_{m,crit} = \frac{0.78b^2}{hl_{ef}} E_{0.05}, \tag{3.28}$$

where b is the width of the beam; and h is the depth of the beam.

For the cases where only moment M_y exists about the strong axis y, the stresses should satisfy the following conditions according to EN 1995-1-1:

$$\sigma_{m,d} \leq k_{crit} f_{m,d}, \tag{3.29}$$

where $\sigma_{m,d}$ is the design bending stress; $f_{m,d}$ is the design bending strength; and k_{crit} is a factor which takes into account the reduced bending strength due to lateral buckling.

Table 3.3

Effective Length as a Ratio of the Span According to Eurocode 5 (EN 1995-1-1:2004 + AC:2006 + A1:2008)

Beam type	Loading type	l_{ef}/l [a]
Simply supported	Constant moment	1.0
	Uniformly distributed load	0.9
	Concentrated force at the middle of the span	0.8
Cantilever	Uniformly distributed load	0.5
	Concentrated force at the free end	0.8

[a] The ratio between effective length l_{ef} and span l is valid for a beam with torsionally restrained supports and loaded at the centre of gravity. If the load is applied at the compression edge of the beam, l_{ef} should be increased by $2h$ and may be decreased by $0.5h$ for a load at the tension edge of the beam.

The value of k_{crit} is determined according to EN 1995-1-1:

$$\begin{gathered} k_{crit} = 1.0 \text{ for } \lambda_{rel,m} \leq 0.75, \\ k_{crit} = 1.56 - 0.75\lambda_{rel,m} \text{ for } 0.75 < \lambda_{rel,m} \leq 1.4, \\ k_{crit} = \frac{1}{\lambda_{rel,m}^2} \text{ for } 1.4 < \lambda_{rel,m}. \end{gathered} \tag{3.30}$$

For the cases where a combination of moment M_y about the strong axis y and compressive force N_c exists, the stresses should satisfy further condition according to EN 1995-1-1:

$$\left(\frac{\sigma_{m,d}}{k_{crit} f_{m,d}}\right)^2 + \frac{\sigma_{c,0,d}}{k_{c,z} f_{c,0,d}} \leq 1.0, \tag{3.31}$$

where $\sigma_{m,d}$ is the design bending stress; $\sigma_{c,0,d}$ is the design compressive stress parallel to grain; $f_{c,0,d}$ is the design compressive strength parallel to grain; and $k_{c,z}$ is determined according to Equation 3.22.

3.2.3. Serviceability Limit States

Properly designed timber structural elements should also satisfy serviceability limit state requirements according to EN 1995-1-1. Requirements for elements in terms of serviceability are provided in EN 1995-1-1, Section 7. Next to the elastic deflection restrictions, creep deflection should also be satisfied throughout the lifespan of the building.

The main components of simply supported beam's deflection are provided in Fig. 3.8, according to EN 199-1-1.

The symbols in Fig. 3.8 are defined as follows:

w_c is the pre-camber (if it is applied);

w_{inst} is the instantaneous deflection;

w_{creep} is the creep deflection;

w_{fin} is the final deflection;

$w_{net,fin}$ is the net final deflection.

The net deflection below a straight line between the supports, $w_{net,fin}$, should be determined according to EN 1995-1-1:

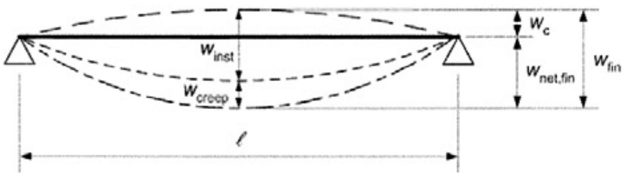

Fig. 3.8. Components of deflection (EN 1995-1-1).

$$w_{\text{net,fin}} = w_{\text{inst}} + w_{\text{creep}} - w_{\text{c}} = w_{\text{fin}} - w_{\text{c}}. \tag{3.32}$$

The recommended limit deflection values are further provided in Table 3.4, according to EN 1995-1-1.

Information on the limiting deflection values is usually provided in the National Annex.

Table 3.4

Examples of Limiting Values for Deflections of Beams

Beam type	w_{inst}	$w_{\text{net,fin}}$	w_{fin}
Beam on two supports	$l/300 \ldots l/500$	$l/250 \ldots l/350$	$l/150 \ldots l/300$
Cantilever beams	$l/150 \ldots l/250$	$l/125 \ldots l/175$	$l/75 \ldots l/150$

3.3. MOISTURE PERFORMANCE

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Usually there is a need to control moisture in building. Reasons for this are assurance of good indoor air quality, durability of material and use of building according to its purpose. In wooden buildings wood as a material is not so durable. Wood has a tendency to decay and get mold in favourable moisture and temperature conditions. Unwanted phenomenon with decay is that strength of wood lowers, and mould is an essential visual disadvantage that causes bad smell and unwanted health effect. Because of too high moisture conditions buildings have lower strength and healthy performances.

The essential requirement for moisture control in Finland is as follows:

Moisture must not cause damage to building and must not cause harmful healthy effect for inhabitants!

3.3.1. Use Purpose of Building, Demand for Moisture Control

In public buildings there are many alternative suspended use purposes. The selected use purpose will guide the designing process. It should also be taken into account in architectural design. To meet the demand for moisture control, some reasons in use purpose will arise. Reasons that increase the demand for moisture control are as follows:

- narrow limits in relative humidity of indoor air;
- high moisture product because of use of building;
- low or high indoor temperature;
- situational moist weather condition.

Narrow limits in relative humidity of indoor air will be a reason because some use purpose of building will require that. One example is museums.

In museums, there are narrow limits in indoor air relative humidity because decaying or aging effect should be as small as possible. In museums there should be no corrosion of steel or moisture deformation of wooden material. This leads to a limited value of RH = 40–50 % in museums.

Moisture product might be high in buildings where we use water, or we use water in a process to produce something. One example of building where moisture product is high is a swimming centre. Moisture product in indoor air might be many kilograms per hour because of evaporation from the swimming pool or wet floor.

Low indoor temperature increases the need for moisture control because normally we lower moisture by ventilation and if we have low indoor temperature, we can use ventilation to lower moisture only for a limited time in year. For example, in an ice rink indoor temperature normally is 5–10 °C, and in a warmer season ventilation will increase moisture inside and dehumidification should be done in a different way.

Situational moist weather conditions are depending on geographical location of the building. Outer moisture load will be increasing near the sea. Of course, it is not so simple, and because of that locational weather data is an important input in the designing process. Indoor air quality demands moisture control.

Indoor air quality criteria are high in public buildings. The reason for that is the diversity of users. Among those there are probably some people who are extra sensitive to impurities in indoor air. The biggest problem usually is indoors because of microbial growth in the building. To confuse this a little bit, not all microbial growth is harmful. There is no clear scientific distinction between illness and microbial growth in buildings and structures. World Health Organization [WHO] has issued guidelines about dampness and mould. The guidelines were written by a group of authors and prove that there is lots of knowledge about dampness and mould with healthy effect but still there is not enough information to explain all empirical findings (WHO, 2009).

However, there is common understanding that microbial growth lowers indoor air quality (WHO, 2009). In fresh building material there is no microbial growth, but there is a risk for microbial growth if temperature and relative humidity is high and there is a nutrient in the building material for microbes (Fig. 3.9). Of course, microbial growth also needs time. In wood there is a nutrient for microbial growth, so if temperature and humidity conditions are

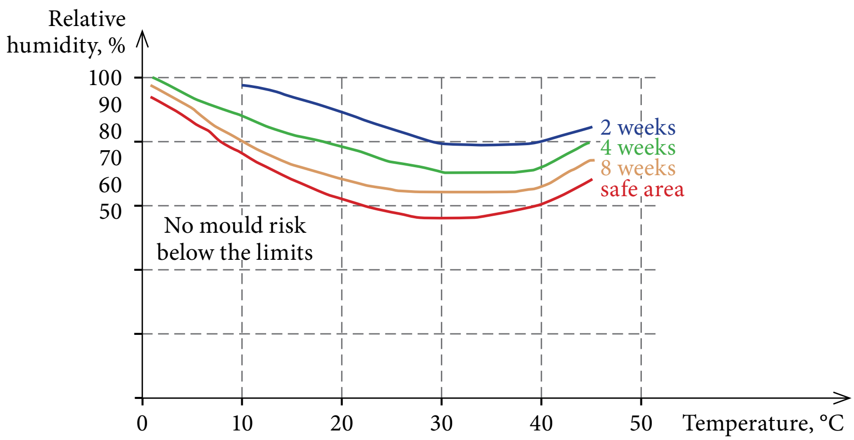

Fig. 3.9. Mould growth dependency on temperature and relative humidity (Viitanen, 2008).

high enough, microbial growth will start eventually. If relative humidity RH is less than 75 %, there is no possibility for microbial growth at all. The limit is dependent on microbial species. Usually the limiting value for mould growth in a building material is 75–80 %.

There are some variations of critical relative humidity in different materials (WHO, 2009). For example, critical relative humidity of concrete is 90–95 %. More cases of critical relative humidity are presented in Table 3.5.

Table 3.5

Critical Relative Humidity for Various Groups of Material (WHO, 2009)

Material group	Relative humidity, %
Wood and wood-based materials	75–80
Paper on plasterboard	80–85
Mineral insulation materials	90–95
Extruded and expanded polystyrene	90–95
Concrete	90–95

To avoid the mould growth, it is necessary to lower relative humidity. As we can see from Fig. 3.9, the average time of mould starting to grow is lower when relative humidity and temperature rise. In buildings there is usually a risk of mould growth and the risk level should be kept down.

It is impossible to keep dry some parts of buildings. For example, façade, roof structure and surfaces in wet rooms are sometimes in direct contact with liquid form of water. Therefore, relative humidity will be higher than the critical level. To avoid mould growth in those structures, it is necessary to insulate the material or surface coating.

If there is no possibility to avoid microbial growth totally in the material, it is necessary to ensure indoor air quality using a different method.

According to WHO Guidelines (WHO, 2009, p. 94) there are no health-based limited values for microbial contaminant because the relationship between dampness, microbial exposure and health effects cannot be quantified precisely. But dampness and mould-related problems increase the risk of hazardous exposure, and according to the guidelines it is recommended that dampness and mould-related problems shall be prevented.

3.3.2. Durability of Wooden Material, Demand for Moisture Control

Durability of wooden material is threatened because of biological reasons. These biological reasons are microbial growth, insects and termites. There are some fungal species that destroy wood. Some insects can make holes in wood and also termites do the same.

Durability of wooden material is threatened because of microbial growth if moisture and temperature conditions are suitable. This microbial growth is related to decay (wood-rot).

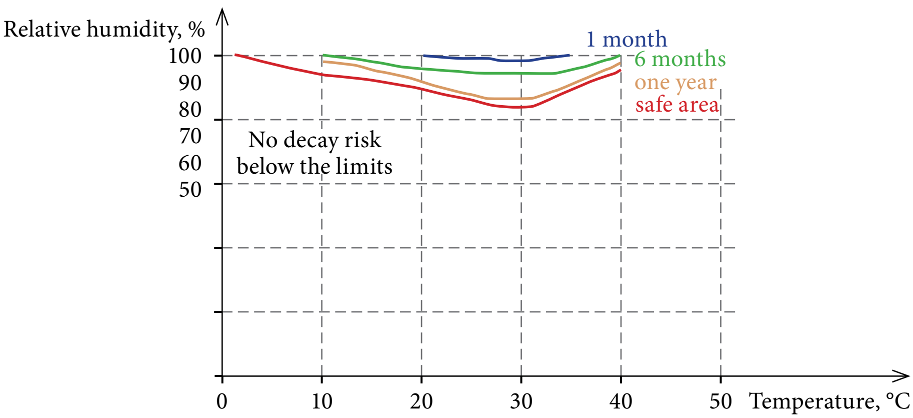

Fig. 3.10. Dependency of decay of wood on temperature and relative humidity.

There are some microbial species that destroy wood. These species normally affect decay. The decay of wood is not possible if relative humidity is less than 90 % (Fig. 3.10).

Also, damages can be happening in wood because of insects and termites. Some insects can destroy wood. These are usually beetles. Some species make holes in wood if the relative humidity is more than 60 %. Some beetles make holes in dry wood. If wood is weak because of decay, there are more species that can live in wood. Also, some insects can live in the bark of wood. With moisture control it is possible also to avoid damages caused by insects.

Durability of wood against decay fungus can be classified in durability classes according to standard EN 15083-1 (CEN/TS 15083-1:2005). There are 5 durability classes. The durability class is determined according to mass loss in a decay test. Durability classes and descriptions are presented in Table 3.6.

Table 3.6

Durability Classes of Wood and Wood-based Products (CEN/TS 15083-1:2005)

Durability class	Description	Percent loss in mass
1	Very durable	≤ 5
2	Durable	> 5 to ≤ 10
3	Moderately durable	> 10 to ≤ 15
4	Slightly durable	> 15 to ≤ 30
5	Not durable	> 30

From biological durability aspect there are differences between wooden species. In Finland wooden species pine (*Pinus silvestris*) and spruce (*Picea abies*) are usually listed in durability class 4 – slightly durable. Many other Nordic wood species like birch, alder, aspen, beech, and maple are in durability class 5 – not durable (Viitanen, 1997). Also, there is difference between durability of heartwood and sapwood. Heartwood is more durable compared with sapwood.

With different kind of treatments, it is possible to raise the biological durability. Those treatments are physical and chemical. An example of physical treatment is thermal modification and an example of chemical treatment is pressure impregnation.

In Finland, for example, some wooden species are not used as a frame material. Mostly pine and spruce are used as a frame and facade material.

3.3.3. Moisture Control in Construction Process

It is possible to avoid moisture damage in many different ways. As explained before, moisture can influence indoor air quality and lower strength of wood. It is possible to affect that with architectural design, structural design, construction process and maintenance of the building.

With architectural design it is possible to affect much because an architect usually has a great influence on the geometry of building, selects surface material of the building and initial construction types and design spaces for different use purposes. These are all important because they affect the difficulty class of structural design. The geometry of building affects the external moisture load to facade. If the facade is of wood material, eaves will have a high effect on how much wind driven rain there is to the wooden facade. Also, usually an architect recommends structural types for the structural design of the building. Usually, it is wise to use well known structure types with good experience, but that is not always possible. If there is a need to make something new, it usually means extra costs for structural design, construction workmanship and extra time for construction process to control moisture suitability. Indoor surface material also might affect moisture control. Some surface materials need moisture control to avoid moisture deformation of material. Also, some surface materials have effect on moisture flows because of moisture vapor resistance of the material layer.

With structural design we design load bearing structures and also thermal and moisture insulations and other materials and building products of the building. Thus we ensure health, energy efficiency and durability of the building. That part might be separated from building physical design. With structural solution we should control inner and outer moisture load to keep structures dry enough. For example, in wall structures we use a vapor barrier to stop moisture vapor move with diffusion and use outer claddings with ventilation air cap to stop rain water to penetrate into the structure and so on. Also, the selected structures should be fault-tolerant with a low risk for moisture damage. Fault-tolerance means that if there is a small error in construction drawings, construction workmanship, use of building or maintenance, the structures are tolerant to that. Therefore, to use structures and details with good experience is wise. In structural design we select products for structures or by clear performance criteria for materials. Wooden material should be selected to be durable for moisture conditions in the future.

With HVAC design we can affect indoor air temperature, moisture and air pressure distribution conditions. These will affect the inner moisture load condition of structures.

Construction workmanship is also critical for moisture durability of wooden material. In construction process material should keep dry enough and construction should be done as structural designer has planned to achieve the designed moisture performances. So, we should protect material from rain water and humid air. This is a quality level of workmanship. During construction there might be much building moisture that should dry during the construction process. During construction properties of moisture tolerance of building materials will affect how careful the construction workmanship should be during construction. In Finland it is required to make a moisture controlling plan of the construction process.

3.3.4. Moisture Control in Structural Design

Structural design includes thermal insulation of envelope, air tightness of envelope, rain tightness of roof and facades, ventilations in structures, moisture barriers, and so on. In Europe there is no standard system for that, but there are standards for different materials and products. This kind of design can be recognized by an expert of building physics.

Geometry of building, surface material and use purpose of different space will affect how complicated the structural design is. That is also a reason why the structural designer gives feedback to the architect about how difficult it is to design and build the structure without a risk of moisture problem. The easiest form of building is usually a cubic form with a high sloped roof with long eaves.

Moisture performance is also connected with strength and stability because moisture content of wood affects the strength properties of wood.

The design solutions for moisture performance in structural design can be of different difficulty classes. If there is nothing special, the difficulty class is ordinary and standard procedure is possible. If the demand for moisture performance is high, or there is need to develop something, the difficulty of moisture design is higher, and it is necessary to use a performance-based design.

Standard moisture performance design

At a normal level a good moisture performance of the whole building and structural types will be selected using a well-known structural solution with good empirical experience. These solutions may depend on the use purpose of the building and on national climatic conditions. Some material suppliers have libraries of examples of structural types on their web page. For example, Finnish Wood Research Oy has worked out a harmonized open standard for wood structure RunkoPES 2.0. (Puuinfo, 2020). There are also structural type drawings with energy, moisture, fire and sound performances.

Performance based moisture performance design

In more general moisture design, there is input data that has an effect for structural design. These input data are:

- climatic conditions in the location where building will be built;
- use purpose and maintaining method of the building.

Climatic conditions will generate **outer moisture load** to the building. Outer moisture load comprises rain, wind driven rain, air humidity, runoff water, ground water and flood.

The use purpose of building affects the **inner moisture load**. Inner moisture load usually is water vapor that rises because of evaporated moisture product to indoor air. In wet rooms inner moisture load is a water vapor product and also is influenced by water flow.

Performance based moisture performance design

Moisture performance of the whole building can be compared with the performance criteria of moisture tolerance. Moisture tolerance can be evaluated with risk analysis in difficult cases where there is no experience (Hens, 2013b). Moisture tolerance should be also taking into account minor faults in workmanship. Moisture performance should be predictable in design process and controllable during and after construction (Hens, 2013a).

Moisture performance should be predictable in design process and controllable during and after construction.

It is possible to predict moisture performance of the whole building by calculations. There are simple calculation methods that can be done in a simple way using pen and paper. Also, there are larger and more demanding calculations which usually need numerical calculation methods. These numerical calculations are usually done on a computer with commercial software. Some of these calculations are standardized. For example, there is a standard on predicting the moisture performance of a building element with steady state and reason of moisture movement diffusion (EN ISO 13788:2007). Also, there is a standard on calculating moisture performance of a building element with numerical method (EN ISO 15026:2012).

3.3.5. Materials and Products to Control Moisture

In structural design we select materials and products for building elements to control moisture. There is a need to know and understand the performance of materials. Various other materials affect the following features of moisture performance of buildings.

1. Vapor barrier

Vapor barrier is usually a membrane with purpose to limit water vapor diffusion. One example is polyethylene film, in Fig. 3.11.

2. Water proofing

There are different kinds of water proofing. Those are liquid form paintable water proofing, flexible sheets of watertight boards. Water proofing is needed to stop liquid form water flow through material (Fig. 3.12).

3. Air barrier

Air barriers control air leakage through the envelope of building. Usually, the

Fig. 3.11. Vapor barrier – polyethylene film.

Fig. 3.12. Brushable water proofing in wet room.

vapor barrier is also an air barrier. Air barrier with tight joints is generating the airtightness of building. In moisture control air barrier is stopping vapor form moisture convection through the envelope. Air barrier can be also a diffusion-open material.

4. Wind barrier

Wind barrier can be a membrane or board. The purpose for wind barrier is to limit the air flow to thermal insulation layer to avoid the loss in thermal insulation.

5. Building component.

3.3.6. Moisture Performance of Building Components

Building components are floor, outer wall, roof, sealing and intermediate wall and floor structures. These have performances related to moisture. Moisture tolerance of a timber framed building component is of big interest.

Moisture tolerance of building elements

Because of water sensitivity of the wood, timber framed constructions are less moisture tolerant compared with massive constructions. To avoid problems, some requirements are presented in book Performance Based Building Design 2 (Hens 2013b, p. 17).

1. Building moisture in studs, plates and joist must dry without damage.
2. Once the construction is finished, rain should no longer seep in and humidify either the sheathing or the timber frame.
3. Studs and plates should not suck water out of capillary porous materials they contact.
4. Annual cumulating interstitial condensate is not allowed, while a too high winter relative humidity lifting moisture ratio in the sheathing and frame beyond 20 %/kg is excluded.
5. Solar driven vapor flow giving moisture build-up in the insulation and moisture deposit against the air and vapor retarder or the inside lining should be avoided.

Structures above foundation can be timber framed structures.

For **floor structures** there are some ways to meet the requirements for moisture tolerance. The floor structure can be with crawl space or plate on ground. The floor structure has a moisture risk because of ground water, capillary moisture in soil, seeping rain water, building moisture and high inside relative humidity. The ground under the building is moist up to relative humidity in the soil reaching 100 % (Hens 2013a, p. 91.)

It is possible to use wood, at a least partly, in floor structures. Risk for mould because of moisture loads should be checked. In Finland, wooden floor structures are usual in floors above crawl spaces but very rare with floors on ground.

Wooden wall structure usually is a timber frame wall structure, CLT frame wall structure or log wall. The walls are with a moisture load of rain and water vapor outside and inside. Also, capillary suction from foundation should be cut before the wooden part.

Wooden facade is constantly in outer weather. Durability of a wooden facade depends on climatic condition and moisture tolerance of wooden material. The rain load to facade depends on the situation, height, direction and eaves of building.

Timber frame should be protected from seeping rain water. Timber frame and CLT-frame is usually protected with facade and ventilated air cap with drainage. Log wall can be without facade, at least in Finland. The design of rain protection of wall structure depends on the load of wind driven rain.

To avoid interstitial condensation and to control the relative humidity inside walls structure, there can be a vapor barrier with necessary moisture resistance. The dimension and the right place of vapor barrier can usually be calculated with Glaser method (EN ISO 13788:2007). In Glaser method water diffusion calculation is done in steady state situation. Sometimes in order to dimension the vapor barrier it is necessary to take into account also the hygroscopic property of the material. In that case there is need to make calculation by the time-dependent method. That means numerical calculation with software where the calculation is based on the difference or element method.

Also, air infiltration should be taken into account when we are estimating the moisture tolerance of wall structure. Because of that there usually is the requirement for air tightness of building element and air pressure difference level between indoor air and outdoor air.

There are also windows and different kind of details in the wall. In the connections between the wall and window there are details where also rain tightness, drainage and ventilation of wall structure should be designed.

The envelope of a building comprises also roof and top bottom structures. The purpose of a roof structure is to lead rain water outside of walls or to drainage. There are different kinds of roof structures. The main types are low pitched roofs and high-pitched roofs (Ahola, 2013). Difference between these is in slopeness and water proofing methods. In low pitched roof slopeness is less than 1:10 and water proofing is continuous. Usually that is achieved with bitumen membranes. In high pitched roof, water proofing is based on roofing material, underlay and slopeness. Under the underlay there usually is a ventilation space or cavity. The roofing material of high-pitched roofs usually is a bituminous layer, sheet metal or clay or concrete tiles. That can be also wood. For example, wooden tile roof was used historically in churches in Finland, and there were thatched roofs in Denmark (Fig. 3.13).

Under roof there is top bottom with thermal insulation. The requirement for top bottom is to avoid interstitial condensation and mould by vapor barrier and air tight layer.

In roof and top bottom structure there can be also roof windows or a glass roof. Connection between roof windows and other roof structures are special places with high risk of moisture damage.

Fig. 3.13. Thatched roof in Denmark, Odense.

3.3.7. Moisture Tolerance of Wooden Structure According to the Use Class and Biological Durability Class of Wood

By moisture control it is possible to generate dry environment for users and also for the building material. In standard EN 335:2013 the use classes for timbers are defined. Those use classes are UC1 to UC5.

- USE class 1 (UC1) Indoor
- Use class 2 (UC2) Condensation can occur
- Use class 3 (UC3) In rain:
  - UC3.1 not remain wet for long period
  - UC3.2 will remain wet for long period
- Use class 4 (UC4):
  - Direct contact to ground of fresh water
  - Disfiguring fungi and wood-destroying fungi are possible
- Use class 5 (UC5):
  - Direct contact with sea water

These use classes are classified according to biological risk caused by disfiguring fungi, wood destroying fungi, beetles, and termites (Table 3.7).

Table 3.7

Summary of Use Classes and Relevant Attacking Biological Agents of Wood and Wood-based Products

Use class	General use situation	Occurrence of biological agents				
		Disfiguring fungi	Wood-destroying fungi	Beetles	Termites	Marine borers
1	Interior, dry	–	–	U	L	–
2	Interior, or under cover, not exposed to the weather. Possibilty of water condensation	U	U	U	L	–
3	Exterior, above ground, exposed to the weather. When sub-divided: 3.1 limited wetting conditions 3.2 prolonged wetting conditions	U	U	U	L	–
4	Exterior in ground contact and/or fresh water	U	U	U	L	–
5	Permanently or regularly submerged in salt water	U	U	U	L	U

U – ubiquitous in Europe and EU territories
L – locally present in Europe and EU territories

These use classes as examples are presented in Fig. 3.14.

For different use classes there are guidelines for selecting wood species related to biological durability in European standard EN 460:1994. All wood species are durable enough in indoor climate, Use class 1 (Table 3.8).

Table 3.8

Guidance on Durability Classes of Wood Species for Use in Different Use Class (EN 460:1994) (Note that hazard class is marked as a use class nowadays)

Hazard class	Durability class				
	1	2	3	4	5
1	o	o	o	o	o
2	o	o	o	(o)	(o)
3	o	o	o	(o)–(x)	(o)–(x)
4	o	(o)	(x)	x	x
5	o	(x)	(x)	x	x

Key:

o	natural durability sufficient;
(o)	natural durability is normally sufficient, but for certain end uses treatment may be advisable (see Annex A);
(o)–(x)	natural durability may be sufficient, but depending on the wood species, its permeability and end use (see Annex A), preservative treatment may be necessary;
(x)	preservative treatment is normally advisable, but for certain end uses natural durability may be sufficient (see Annex A);
x	preservative treatment necessary.

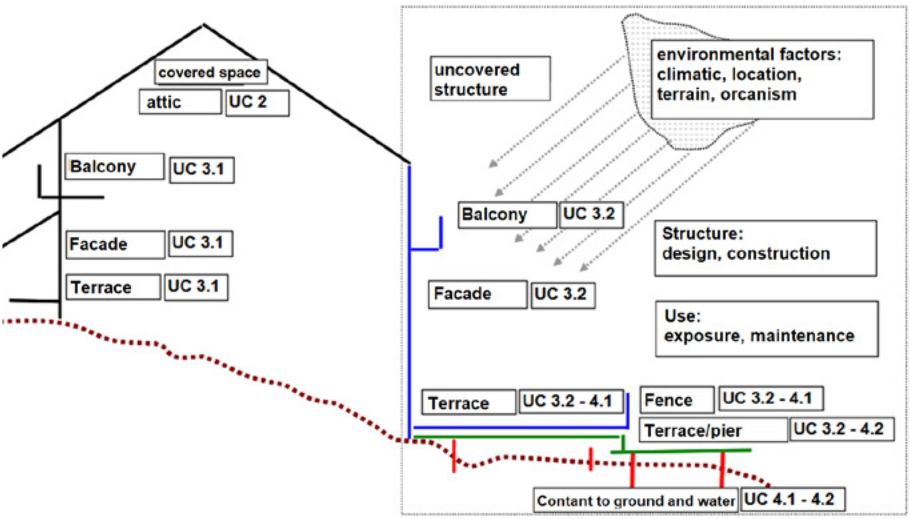

Fig. 3.14. Structures and use class examples (Adapted and translated from (Viitanen, 2004)).

Durability of wood is related to use class and durability class of wood or wood product. Also, those are related to climate. In Fig. 3.15 the factors affecting durability are presented.

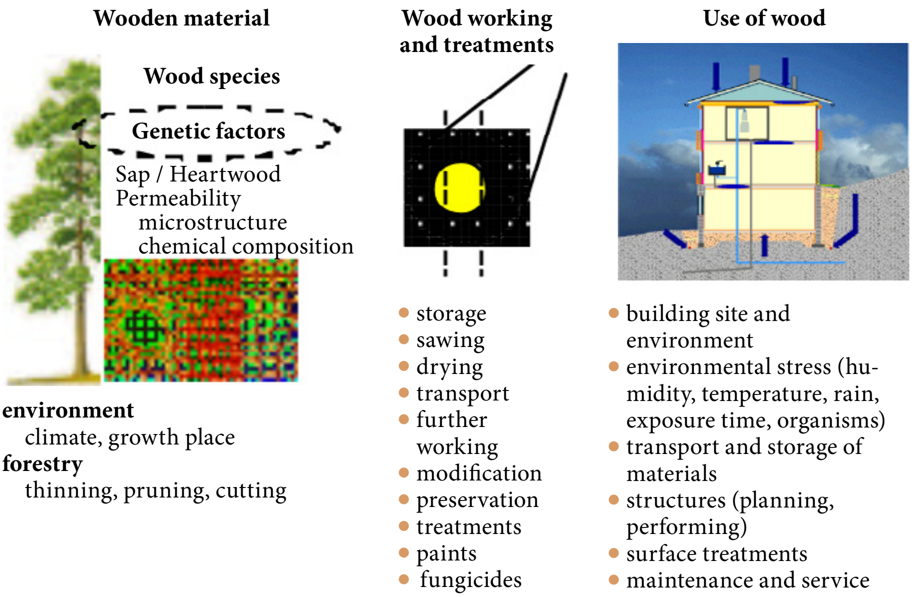

Fig. 3.15. Factors affecting durability of wooden products (Viitanen et al., 2006).

In design we select structures with materials and check that moisture tolerance is filling. For wooden structure procedure is presented in Fig. 3.16.

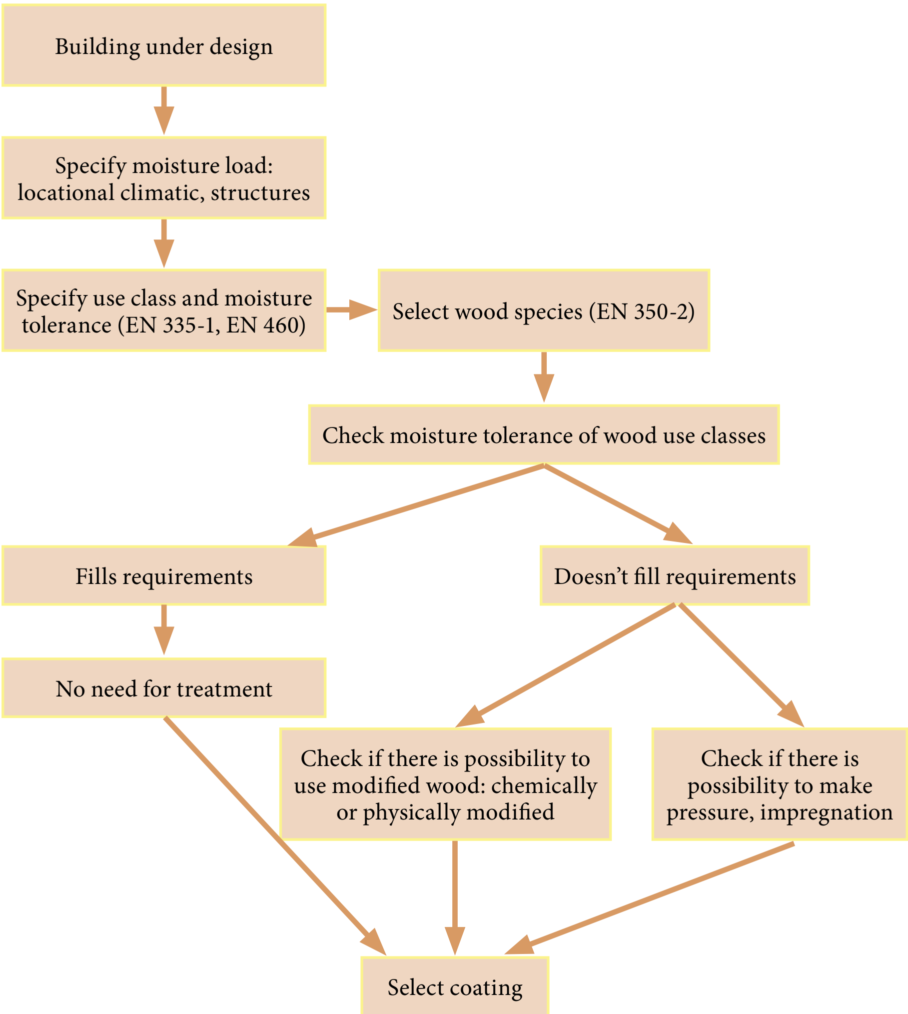

Fig. 3.16. Procedure of selecting wooden species and treatment for using wood in building (Adapted and translated from Viitanen, 2008).

3.4. FIRE SAFETY

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Häme University of Applied Sciences

3.4.1. Fire Safety in Wooden Public Buildings

Public buildings are spaces and also part of the image of an organization (Fig. 3.17). Therefore, they are also subject to high safety, environmental and landscape standards. Public buildings typically have a lot of users not familiar with its safety solutions. Human risks are significant.

Uninterrupted operation and public image are also important in risk management of public buildings. Requirements for the climate impact of construction have increased and favoured wood construction. There is a demand for fire safe wood construction.

Fig. 3.17. Pilke building, photo Jussi Tiainen, design Arkkitehtityöhuone Artto Palo Rossi Tikka Oy.

3.4.2. Fire Properties of Wood

Wood is a flammable and combustible material. Wood pyrolyzes under the influence of heat. As the temperature rises to 160–180 °C, the lignin and celluloses in the wood begin to decompose. Decomposition intensifies when the material reaches a temperature of 270 °C. When the temperature is 350–360 °C, the surface ignites from a small flame or spark. External radiant heat heats the surface. The temperature at which the surface ignites from a small flame or spark is reached at a heat radiation intensity of about 12 kW/m^2. An impinging flame can ignite wood as low as 4 kW/m^2 heat fluxes. The spontaneous ignition requires a temperature of approximately 600 °C.

Moisture in wood is removed by evaporation when the temperature of the material rises to 100 °C. Thermal energy is required to evaporate the water. Heat of combustion of dry wood is 17.5 MJ/kg. If the moisture content of the wood is 10 %, the heat of combustion decreases to 12–14 MJ/kg.

There are two main reaction pathways of thermal decomposition of wood, tar- and char-forming reactions. Gaseous pyrolysis products burn with flame and solids with smouldering. Combustion starts when the pyrolysis

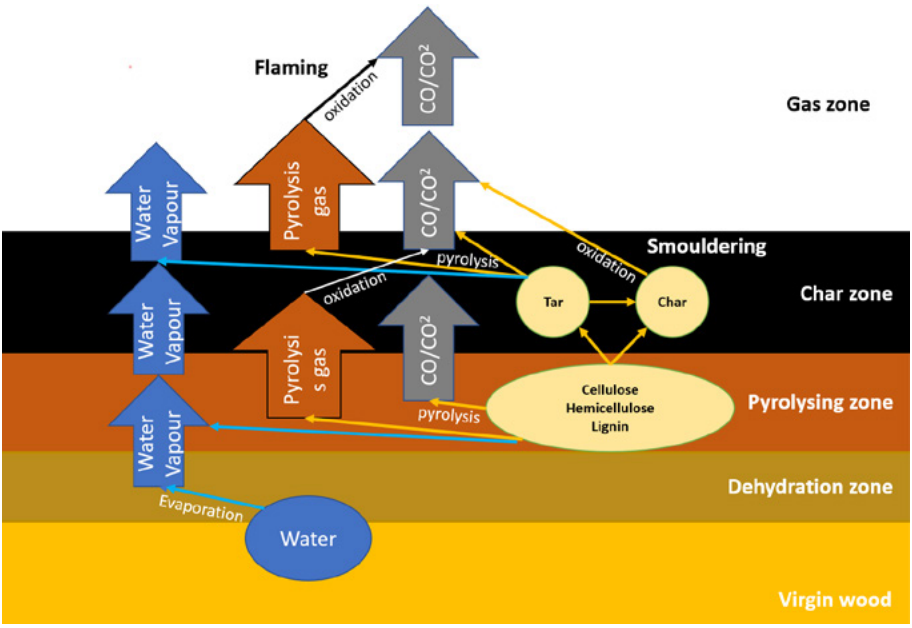

Fig. 3.18. Processes within a burning timber (modified from Bartlett et al., 2019).

products react with oxygen and produce more heat causing a growing chain reaction. The energy released in the reaction heats the burning surface and its surroundings. The fire spreads on the surface as it heats up sufficiently. A value of the charring rate of wood is typically 0.5–1 mm/min. With a load-bearing structure, charring reduces load-bearing capacity.

Charring wood acts as a fuel for fire. The burning rate of the wood is higher soon after ignition, being in the order of 200 kW/m^2. Later, charring protects the wood and slows down the fire. Thin wood surfaces can burn through, causing the burning rate to increase again (Fig. 3.18).

3.4.3. Fire Classification of Wood

Fire test and fire classifications have been harmonized on the EU level. Building materials are divided into categories based on how they ignite and spread fire. The smoke production of the material and the tendency to drip flaming droplets or particles are also defined. Fire classification of construction products is made according to classification standard EN 13501-1:2019. The test methods and classification criteria for fire classes are presented in it.

Tests for material properties are EN ISO 1182:2010 (non-combustibility) and ISO 1716:2018 (calorific value). The flammability properties of the product are determined in accordance with test standards EN 13823:2020 (SBI – single burning item (Fig. 3.19)) and EN ISO 9239-1:2010 (burning behaviour of flooring). Mounting and fixing affects the validity of the classification.

Materials are classified by test in main Classes A1, A2, B, C, D, E and F on the basis of the above. Classes for floorings are $A1_{fl}$, $A2_{fl}$, B_{fl}, C_{fl}, D_{fl}, E_{fl} and F_{fl}. Additional classes exist for smoke production – Classes s1, s2 and s3, and for burning droplets / particles – Classes d0, d1 and d2.

Fig. 3.19. SBI test.

The European Commission publishes in the Official Journal of the EC lists of products that can be classified without testing. Many wood products are classified without testing (CWT). Non-fireproof wood products are typically in category D if they are at least 9 mm thick and have a density of at least 400 kg/m^3.

Smoke output of wood is usually Class s2. Wood products thicker than 10 mm are normally classified as d0. Thinner products and plywood may have a rating of d1. This is due to blast burning of thin materials and delamination of glued products.

Structural sawn timber with a thickness exceeding 22 mm and glulam products with a thickness exceeding 40 mm reach Class D-s2, d0. For panels, particle board and OSB, the classification depends on whether there is an air gap behind the product. Without a gap, the classification is D-s2, d0 and with a gap D-s2, d2. Wood floors are typically in class Dfl-s1.

3.4.4. Flame Retardants for Improving the Fire Properties of Wood

When unprotected wood burns, pyrolysis produces a lot of tar, which decomposes under the influence of heat into easily combustible gases. Wood flame retardants affect pyrolysis. The wood product is treated with a substance that promotes the carbon reaction pathway instead of tar. In practice, the shielding reduces the amount of pyrolysis products burning in the flame and thus also the heat released. Agents that affect the pyrolysis of wood are typically phosphorus or boron compounds.

The classification of fire-protected wood is determined by tests. The tests are performed according to the standard. Fire protection treatment can significantly reduce heat output values, allowing fire classifications to be transitioned from Class D to Classes C and B. This allows wood to be used more widely in different parts of the public buildings.

The protection of a wood product can be significantly reduced if the wood material is exposed to moisture or weather. Water flowing on the surface, changes in moisture content and UV radiation can reduce the amount of flame retardant in the treated wood material. It is important to ensure the functionality of wood products and the long-term sustainability of their fire protection. The European standard EN 16755:2017 has been developed for this purpose and should be applied. The standard defines three categories of DRF (Durability of Reaction to Fire Performance) for verifying the durability of the fire protection: permanent use in dry indoor areas, permanent use in wet indoor areas, and permanent use in outdoor applications.

Wood can also be covered with cladding fulfil K_2 classes for fire protection.

Fire cladding is having tested ability to protect the wood from the effects of fire for the time indicated in the test. The test is made by EN 14135:2004 standard. Requirements can be set also for other fire properties of the product than fire protection ability.

3.4.5. Design for Fire Safety

Fire safety regulations vary from country to country. Main principles for fire safety are the same for prescriptive and performance-based codes. Principles for fire safety are: occupants shall be able to leave the building or they shall be rescued, the safety of rescue teams shall be taken into account, load-bearing structures shall resist fire for required minimum duration, the generation and spread of fire and smoke shall be limited and the spread of fire to neighbouring buildings shall be limited.

Objectives are safety of life, loss prevention and environmental protection. Strategy for safety of life can be evacuation, suppression of fire or containment contents between occupants and fire. Loss prevention can be done by containment contents or suppression.

Standard concept of fire safety, prescriptive codes

When prescriptive codes are used, building is designed with regard to fire classes and criteria provided by regulations and guidelines. For example, the evacuation safety can be based on both active and passive elements. Greatest distance to the nearest exit, number of exits and dimensions of exits are regulated in prescriptive codes. There are rules for doors, locks and exit lights. Active fire detection and alarm or sprinkler may lower the level of requirements.

Prescriptive codes give fire classes and criteria for building elements. The order codes give the required fire class and criteria for the building components. The materials are tested and the codes define the minimum class needed. There are material requirements, for example for surfaces and structures. Wood can be used within the limits allowed by regulations. Fire-retardant treatment increases the possibilities of use.

If the wood material or wooden structure passes the requirements, it can be used. Fire scenario is usually 834-11:2014 standard fire curve. External fire curve and hydrocarbon curve can also be used. The components must retain required properties under the standard fire for the required time.

Calculation methods based on fire tests can also be used. For example, the fire resistance of load-bearing structures can be calculated by a method based on the rate of charring. In addition to the charring rate, there can be taken into account the properties of the material, such as its delamination.

Suppression systems

Public buildings often use fire safety technology such as fire alarms and suppression systems. Extinguishing systems such as sprinkler and water mist systems are effective in saving lives and property.

Sprinkler system prevents the spread of fire, ignition of surfaces and flashover which make flames through window possible. Therefore, the sprinkler is an effective protector of wooden surfaces both inside and on the facade. That has been taken into account in prescriptive codes which allow more wood surfaces when building has a sprinkler.

3.4.6. Performance based fire safety design

There are many types of buildings and fires. Public buildings typically differ from apartments. A fire does not grow in the same way in a small room and a large hall. The standard fire curve and the solutions based on it may not be very suitable for large spaces. It may be appropriate to design the building or part of it performance based, e.g. Joensuu Areena (Fig. 3.20). Performance-based fire safety planning enables fire safety solutions which are fitting exact for the features of the building.

The building can be made on the basis of pre-approved solutions or by fire engineering methods. In the performance-based way, the acceptability of the results can be proved by evaluating the design against absolute criteria (heat, visibility, etc.) or by comparing the fire safety of the design to pre-accepted reference solution. Comparative analysis can also be done by probabilistic analysis.

CFD and zone model software have been developed for fire simulation. The fire can be simulated and solutions designed based on the simulation results. For example, an evacuation can be planned based on a simulated fire and a calculated or simulated exit time. If the conditions caused by the fire during escape do not become dangerous, the result can be accepted.

When acceptability cannot be found in regulations and tables and there are many different methods, the acceptance criteria and methods used must be defined at the beginning of the process. The documentation of results and methods should be done carefully. There are Nordic and EN standards for process and design.

Fig. 3.20. Joensuu Areena, photo Esko Jämsä, design PRO-ARK.

Detailing

Wood is a flammable material that must be considered when building components are designed of wood. Post-flashover apartment fire can break windows and flames contact the facade (Fig. 3.21). A wooden facade can spread fire on its surface or in an air gap if this is not prevented in the plans. Fire can also spread from the facade to the attic. Retardant treatment or fire stops can be used to improve fire safety.

There is a lot of technology in public buildings. Therefore, there are vertical and horizontal shafts and gaps in the buildings. Fire can spread rapidly in vertical shaft because of stack effect. Also, in horizontal shafts, like attics, fire spreads faster than in normal rooms. In hidden spaces fire is detected slowly and it is difficult to extinguish. It is important to prevent the spread of fire into shafts and other hidden spaces, especially if material is flammable.

The wooden structures are connected to each other and to other structures. The joints must withstand the effects of fire. The details are essential for fire safety and must be done with care. By thorough designing and using the right methods, products and technology, a wooden building will become as fire safe as a building made of other materials.

Fig. 3.21. The flames spread from the broken window to the wooden facade.

3.5. ACOUSTICS AND NOISE-ABATEMENTS

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Acknowledgement

Special thanks to Andy Kerr, Technical sales at Rothoblaas for approval of use of information and associated images.

In construction, there are two categories of sound:

- Airborne noise; air carries the sound energy.
- Structural noise; vibration carries the sound through the structure.

Lightweight timber structures do not have high acoustic performance at low frequencies. This is particularly important with sounds of impact and the transmission of structural vibration through the timber construction. It is essential to stop the spread of vibrations in order to control noise transmission.

Sound insulation is fundamental for a healthy and high quality of life. When looking at acoustics and noise-abatements with timber frame buildings, we can consider three areas of critical technical knowledge needed to reduce the impact:

- resilient profiles;
- soundproofing layers;
- sealing products.

In this section we have collaborated with Italian company *Rothoblaas*. *Rothoblaas* is a world leader and provider of high technology solutions in the construction and wood sector. They develop products and services dedicated to the wood carpentry industry and continue to export know-how from the heart of the Italian Alps to the world. We will examine the products developed by *Rothoblaas* and how they are used.

Resilient profiles

Resilient products are elastic separating layers between rigid elements whose main feature is to prevent the transmission of vibrations in the building structure (e.g. impact such as footsteps) (Fig. 3.22). Working at this level of the structure means being able to solve the problem at the source, allowing greater flexibility and tolerance during processing and modification of the subsequent layers, such as thermal and acoustic insulation or coverings and various kinds of dry linings.

Range of resilient products can be found at: https://www.rothoblaas.com/products/soundproofing/resilient-profiles/xylofon.

A high-performance resilient profile that ensures acoustic comfort in timber structures and houses is made of a polyurethane compound; it is available in 5 versions from 35 to 90 shore, on the basis of the load it has to support.

Tested and certified for use as a desolidarisation and mechanical interruption layer between building materials, it significantly reduces the transmission of airborne and structural noise (up to more than 15 dB).

Fig. 3.22. Resilient profiles (Rothoblaas, 2020).

3.5.1. Cork and Xylofon washers & profiles

Cork is a traditional soundproofing material that significantly reduces airborne and structural noise. It is an ideal solution for sustainable buildings (Fig. 3.23). Cork is waterproof, resistant to damp and does not deteriorate due to load. Soft cork has a lower density and larger dimensions of the granulate, hard cork has a high density and smaller dimensions of the granulate.

XYLOFON washers are a solution for sound insulation which, together with XYLOFON, ensures the continual soundproofing of timber structures (Figs. 3.24–3.26). Other soundproofing products are shown in Fig. 3.27.

Fig. 3.23. Use of cork (Rothoblaas, 2020).

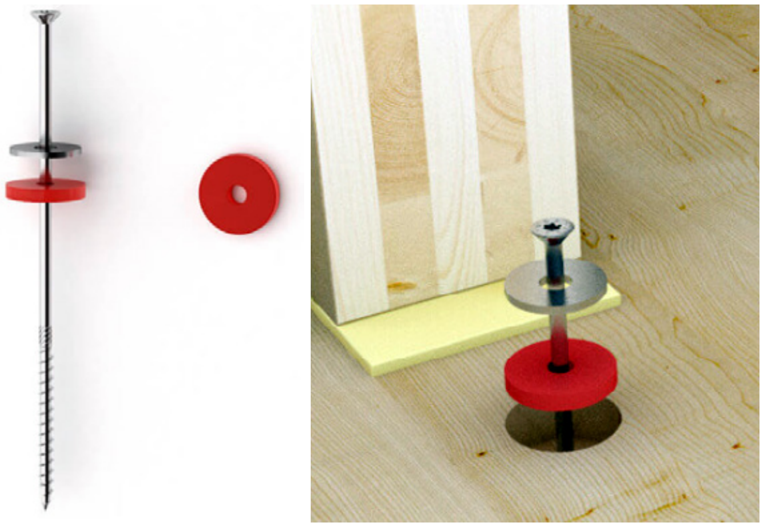

Fig. 3.24. Wood screws separating washer (Rothoblaas, 2020).

3.5.2. Soundproofing layers

Separating soundproof layers or membranes can be used in floors, herewith are several options of materials and how they function within the building fabric.

Silent floor soft is shown in Fig. 3.28.

A resilient under screed membrane made of foil and closed cell PE is shown in Fig. 3.29.

Silent floor: Resilient under screed membrane made of foil with bitumen and polyester felt. This material is ideal for separation between wood and concrete.

The highest performing membrane in the *Rothoblaas* range, Silent Floor Evo, is made with foil and recycled polymers (a polyurethane compound), creating an elasticity which offers performance up to 30 dB (Fig. 3.30).

Fig. 3.25. Separating washer for WHT angle bracket (Rothoblaas, 2020).

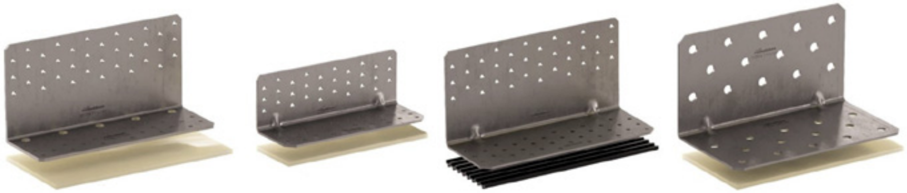

Fig. 3.26. Titan silent; for angle bracket resilient profile (Rothoblaas, 2020).

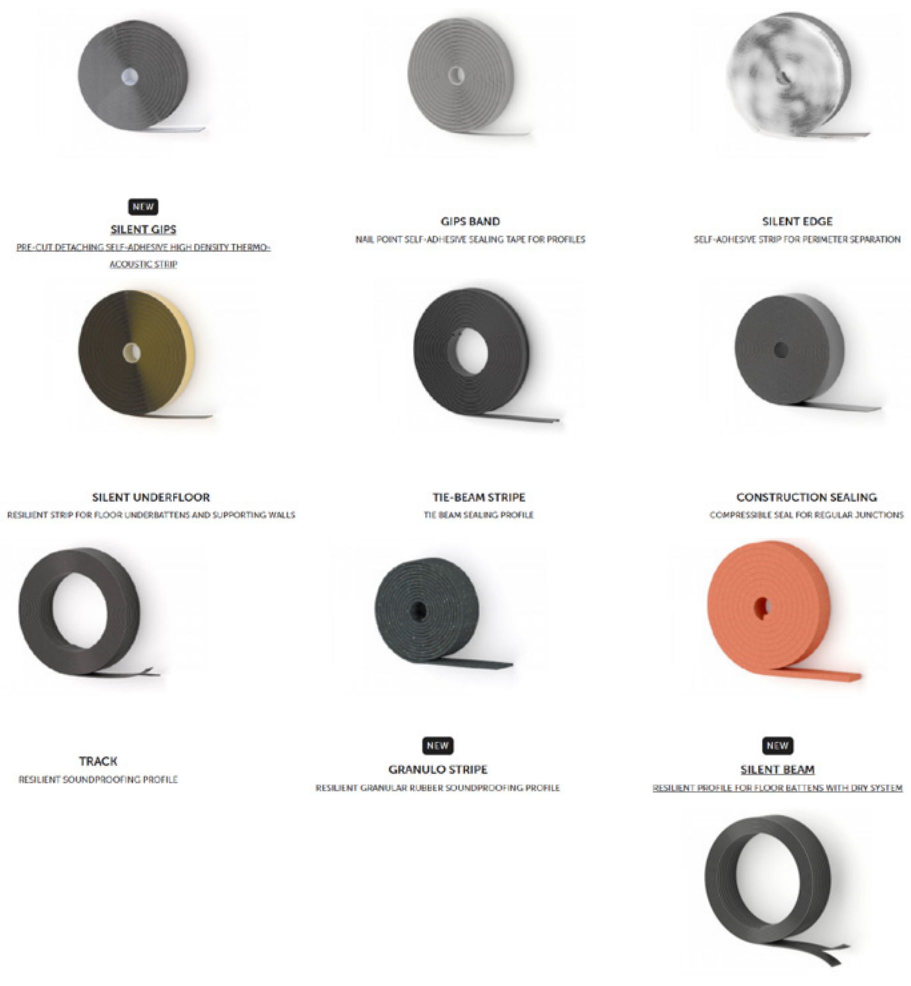

Fig. 3.27. Other resilient soundproofing products (Rothoblaas, 2020).

Fig. 3.28. Silent floor soft (Rothoblaas, 2020).

There are several other materials offered by *Rothoblaas* (Fig. 3.31).

Range of soundproofing layers can be found at: https://www.rothoblaas.com/products/soundproofing/soundproofing-layers.

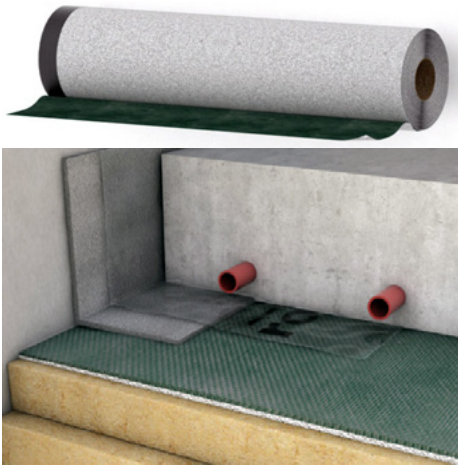

Fig. 3.29. A resilient under screed membrane made of foil and closed cell PE (Rothoblaas, 2020).

Fig. 3.30. Silent Floor Evo (Rothoblaas, 2020).

SILENT WALL MASS
Soundproofing and waterproofing bituminous foil

SILENT WALL
Soundproofing and waterproofing self-adhesive bituminous foil

TRASPIR METAL
3d mats for metal roofs

SILENT STEP SOFT
Substrate made of closed cell PE

SILENT STEP
Substrate made of high density NPE polyethylene with PE film serving as a vapour barrier

SILENT STEP ALU
Substrate of a high density polymer mix covered in aluminium serving as a vapour barrier

SILENT STEP UNI
High density polyurethane substrate with excellent compression resistance

Fig. 3.31. Other materials (Rothoblaas, 2020).

3.5.3. Sealing products

Hermetic foam (Fig. 3.32): A high-performance soundproof elastic sealant foam; it works by ensuring the airtightness of all types of cracks between different materials. The closed-cell structure is watertight and airtight, even after trimming.

Frame band (Fig. 3.33): A self-expanding sealing tape for doors and windows from 2 mm to 10 mm.

Kompri band: A self-expanding sealing tape for use on different materials and irregular shapes and surfaces. It prevents acoustic bridges offering sound reductions of up to 58 dB (Fig. 3.34).

Range of sealing products can be found at: https://www.rothoblaas.com/products/soundproofing/sealing-products.

As a final note, these products should all be used within timber buildings as a standard of good practice and are widely available within the construction sector.

Fig. 3.32. Hermetic foam (Rothoblaas, 2020).

Fig. 3.33. Frame band (Rothoblaas, 2020).

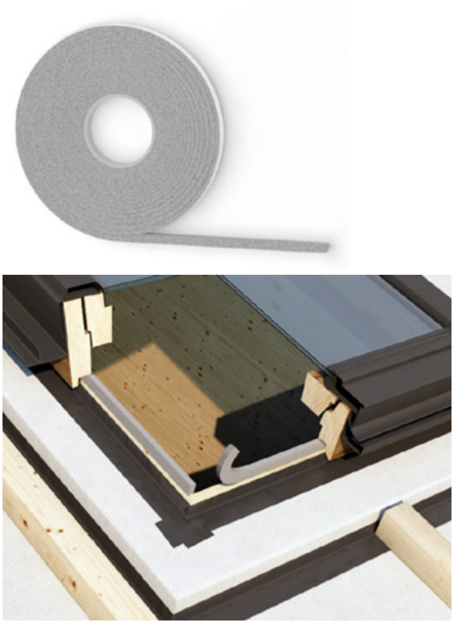

Fig. 3.34. Kompri band (Rothoblaas, 2020).

3.6. DESIGN OF BUILDING SERVICE SYSTEM

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VIA University College

We will discuss how guideways can be established in large buildings built of wood. There will be a focus on how guideways can be established from different installations and the importance of having an overview of collisions. We will look at how breakthroughs can be established.

Breakthroughs in wet rooms will be looked at. There will be a focus on problems around condensation from installations and what significance it may have for the constructions.

This section will also address some of the challenges to be aware of, installations and guideways that can have a major impact on how the building is designed, also over the life of the building.

3.6.1. Solutions in Wood Compared to Concrete Construction

When using wood as walls, beams and decks can provide other solutions for how guide weight can be established than when building in concrete, but at the same time there are also places to be aware of as it can have an impact on the life of the building.

It is important that early in the project it becomes an analysis of the building's requirements and function, so that it is possible to begin an analysis of which technical installations are to be in the building.

Once the requirements and function of the building have been determined, the dimensioning of the technical installations can begin.

Dimensioning of the technical installations is run in parallel with the building being designed.

By running this, dimensioning and projecting the side runs mean that the technical installations are thought into the new building and it will be possible to make some architecturally beautiful solutions.

Each country has its own building regulations, so it is important that each country carefully goes in and considers what requirements there are for the respective countries where the project is to be solved.

In this part of the book, there will be suggestions for solutions that can be used as inspiration, but it is not certain that the illustrated and described solutions are legal in all countries.

So, what installations should be included in a building? If recesses are to be made in, for example beams, the supplier will be able to make these recesses with great precision and often with a tolerance down to 2mm, this means that the holes can be made considerably more precise compared to the traditional recesses in concrete.

Because these recesses can be made with such great precision that it is possible to make very beautiful visible solutions, however, it must be clarified that it is very important that the person sitting and drawing on the project knows exactly what sizes these shafts are. It is important to know what will go through these recesses.

3.6.2. Ventilation

The location of ventilation ducts can have a great impact on the design of a building.

It is important that early in the process you look at the construction and dimensioning of the building's load-bearing system and parallel dimensions of the ventilation system as well as the ducts for the ventilation system.

The ventilation unit is often placed in a separate room due to noise and fire hazard.

The ventilation system is dimensioned in relation to how much air change there must be in the rooms and the respective rooms the system must operate.

The size of the facility can have an impact on the space and the size of the building.

An example is provided in Fig. 3.35 – a building where the ventilation system is located in a technical room, Room 1. The ventilation system must serve Room 2, which is a large room for many people, for example a museum. The building is built up with beams, which is the load-bearing structure for the roof cassettes.

In this example, we will look at different solutions both where the ventilation duct goes through the beam and where the ventilation duct runs under the beams; both options will be assessed, with advantages and disadvantages.

Based on a theoretical calculation, the duct size must have a cross-sectional area of 9600 cm^2 when blowing in (red) and 9600 cm^2 when blowing out (blue) in Fig. 3.35.

What design should the ventilation ducts have?

This can have an effect on the height of the beam, which will be looked at circular ducts, square ducts or rectangular ducts; the design of the ventilation ducts can affect the height of the beams if the ventilation ducts are to run through the beams.

For example, if using a rectangular tube, the dimension can be 80×120 cm = 9600 cm^2 (Fig. 3.36).

If using a square pipe, which must have a cross-sectional area of 9600 cm^2, the duct dimension must be 98×98 cm:

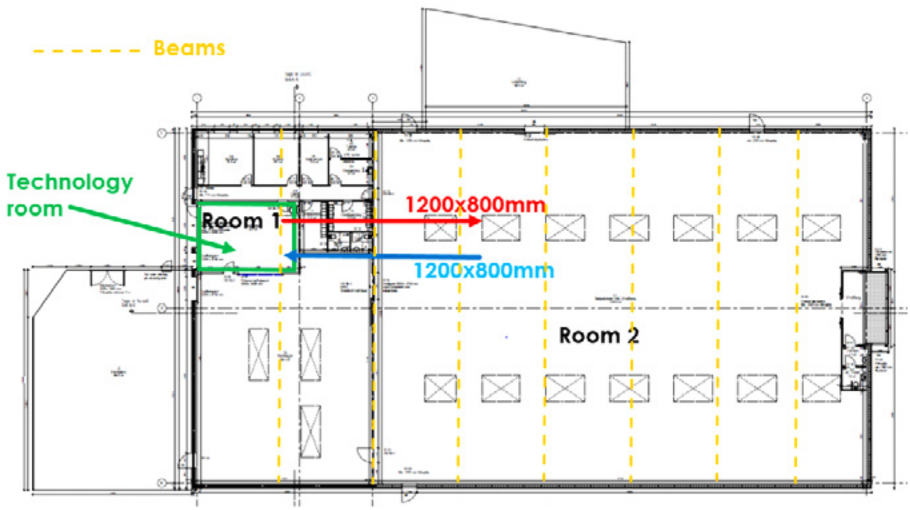

Fig. 3.35. Example.

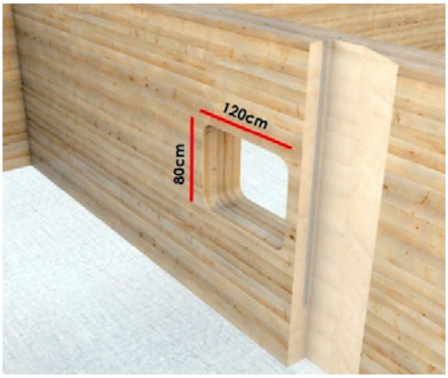

Fig. 3.36. Duct dimension 80×120 cm.

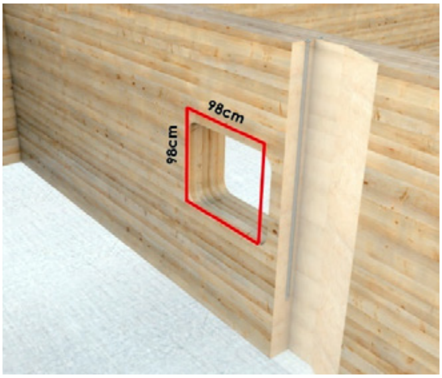

Fig. 3.37. Duct dimension 98 × 98 cm.

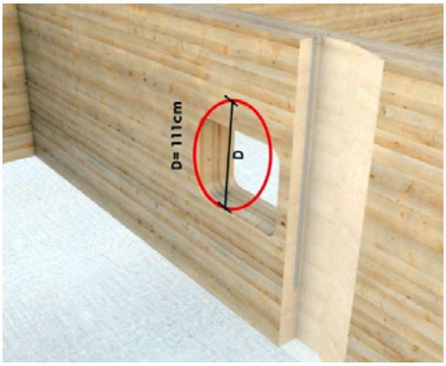

Fig. 3.38. Circular pipe (tall wooden buildings).

$\sqrt{9600}$ = 97.98 cm = 9677 cm^2 (Fig. 3.37).

If a circular pipe is used, the pipe must have a diameter of 111 cm to reach a cross-sectional area of 9600 cm^2:

(111/2) 2π = 9600 cm^2 (Fig. 3.38).

If the ventilation ducts are to break through load-bearing beams, this will have an effect on the dimensioning of the beam, as a breakthrough will reduce the load-bearing capacity of the beam; if the ventilation system is paced under a beam, it will have an effect on the free ceiling height in the building.

So, the design and dimensioning of the ventilation ducts as well as the location of the ventilation ducts can have an important significance for the building.

It will also be possible to split ventilation ducts and reduce the duct sizes, the number of pipes will thereby be increased, by the simple calculation the area

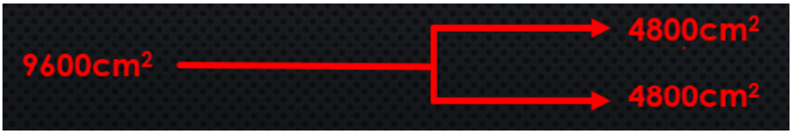

Fig. 3.39. Cross-sectional area.

can be halved; always make a control calculation to ensure that the correct air change comes to the room.

If we work with a pipe being dimensioned for a cross-sectional area of 9600 cm^2 and dividing it into 2 ducts, the cross-sectional area will be half 9600/2 = 4800 cm (Fig. 3.39), which means that the ventilation duct is reduced down to half the area.

By splitting the ventilation duct, it is possible to reduce the total height of the beam.

This is the simple calculation that should always be made to ensure that the respective air volumes are still complied with.

By reducing the height of the beam, the price of the beam will also be cheaper, then it must also be considered that more recesses must be made in the beams, there will be more ventilation pipes and more wages, so there are many things to consider.

Fig. 3.40. Ventilation ducts under the load-bearing beams.

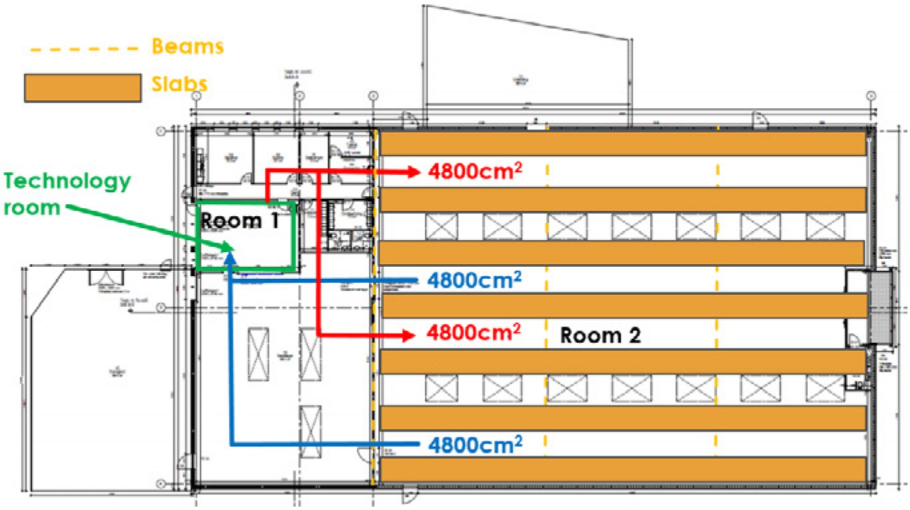

Fig. 3.41. Load-bearing slabs laid at a distance.

But it will also be possible to run the ventilation ducts under the load-bearing beams; by running the ventilation ducts under the load-bearing beams the height of the beams can be reduced to a minimum, however, one must be aware that with this solution the ceiling height is reduced, so the legislation must be checked on whether there is a requirement for a minimum height (Fig. 3.40).

If load-bearing slabs are laid at a distance and closed with a light construction between slabs, it will be possible to reduce the number of load-bearing beams, see Fig. 3.41.

Above the beams and between slabs it will be possible to run installations such as ventilation pipes, fire extinguishing, heating pipes, electric cables (see Fig. 3.42);

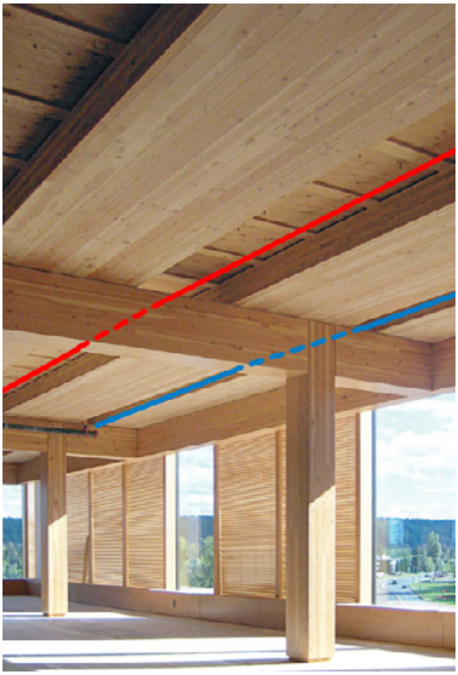

Fig. 3.42. Installations above the beams and between slabs.

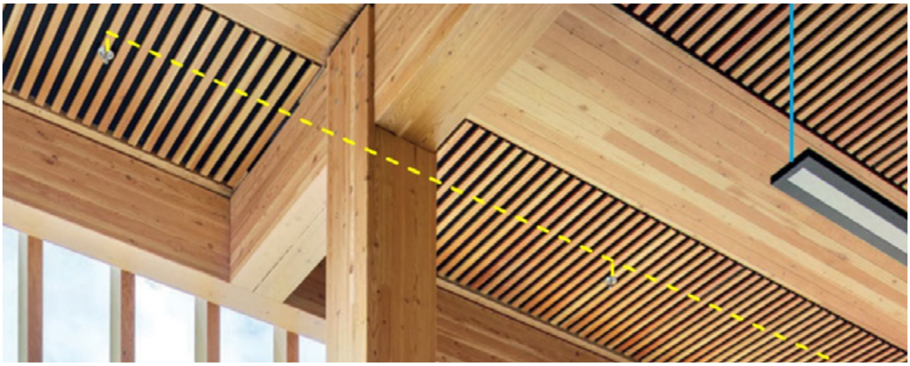

Fig. 3.43. Duct roads closed between the load-bearing CLT slabs.

it makes it easy to inspect these pipes and cable ducts, it will also be possible to hide these duct roads (see Fig. 3.43 – here it is closed between the load-bearing CLT slabs).

3.6.3. Heating

In this section we will look at some of the ways to heat large wooden buildings. Dimensions of the heating system will not be made, but only different possibilities for heating and on guideways for pipes will be looked at.

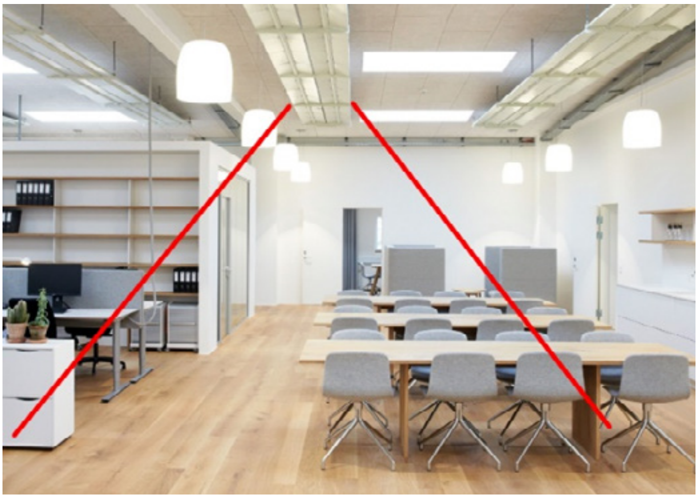

Fig. 3.44. Radiators placed in the ceiling.

Radiators

Radiators can be placed in the ceiling, they emit heat via radiant heat (Fig. 3.44); it is important to assess at what height and how close these radiators are; the piping can either be run visibly or milled into the walls. So, depending on which manufacturer is used, a calculation must be made so that there can be sufficient heat for the people who use the building (Fig. 3.45).

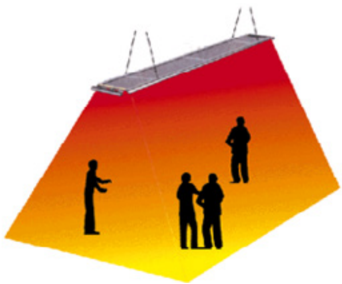

Fig. 3.45. Heating of the premise (Receent, 2019).

It can also be odd to do the heating with radiators placed on the walls by either milling the radiator into so that it is flush with the wall surface (Fig. 3.46) or outside the wall (Fig. 3.47). If the radiator mills into the walls, it will reduce the thickness of the wall where the radiator is located, which can affect the load-bearing capacity of wall elements, fire requirements and sound requirements to ensure that the wall-gen can still maintain.

The piping to the radiator can be placed visible or milled into the wooden construction.

It will also be possible to make underfloor heating. The underfloor heating can be done in light constructions made of wood and aluminum which are

Fig. 3.46. Milling the radiator into wall surface (Hudevad, 2019a).

Fig. 3.47. Radiator outside the wall (Hudevad, 2019b).

located on or between the deck elements. The advantage of this underfloor heating system is that it has a fast effect, so if the temperature rises quickly due to the sun's rays, the thermostat for the floor heating will close and the floor heating will shut down quickly, as only the aluminum plate is heated and this plate is only 1.5 mm thick it will therefore give off the heat quickly.

It can be an advantage to use a concrete construction on top of a CLT cover element. The concrete can maintain the right sound requirements, have a stabilizing ability for the building or a fire technical function. This concrete construction can be used to run a floor heating in the concrete by drawing heating pipes in the concrete, which heat the concrete surface which then gives off the heat to the room.

The concrete has a good ability to accumulate heat from the heating hoses which are embedded in the construction. It is important that when the concrete is cast on top of a wooden element, there is a waterproof membrane between the wood so that no moisture pulls from the concrete slab down into the wooden structure, as this can cause mould in the wooden structure.

Figure 3.48 shows a green waterproof membrane on top of the insulation, which does not allow heat penetrate into the underlying space.

The insulation is built on ESB concrete which has been used for guideways for cold and hot domestic water and conveyance of water for installations.

Pipes that can form condensation, it can be ventilation pipes, cold and hot domestic water, and drain pipes, must be insulated so that no condensation is formed. If condensation is formed, a cover element of wood will be dampened, which will cause degradation of the wooden element.

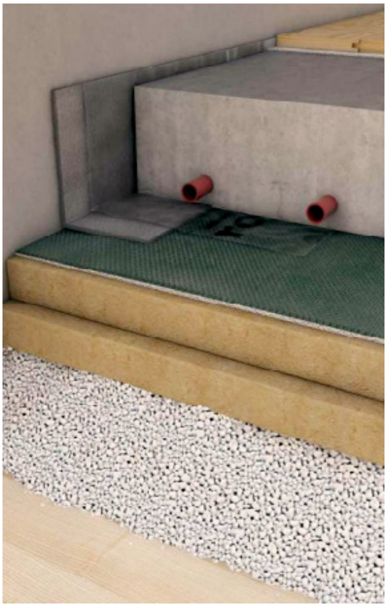

Fig. 3.48. Green waterproof membrane on top of the insulation (Rothoblaas, 2019).

3.6.4. Bathroom

If bathrooms are made of wood, it is important to consider how it is done and what materials are used. There must be the right slope towards the drain that is in accordance with the recommendations for the respective countries, see Fig. 3.49.

The new CLT elements make it possible to mill the rewarding drop into cover elements so that you are sure that the water is led to the drain, see Fig. 3.50.

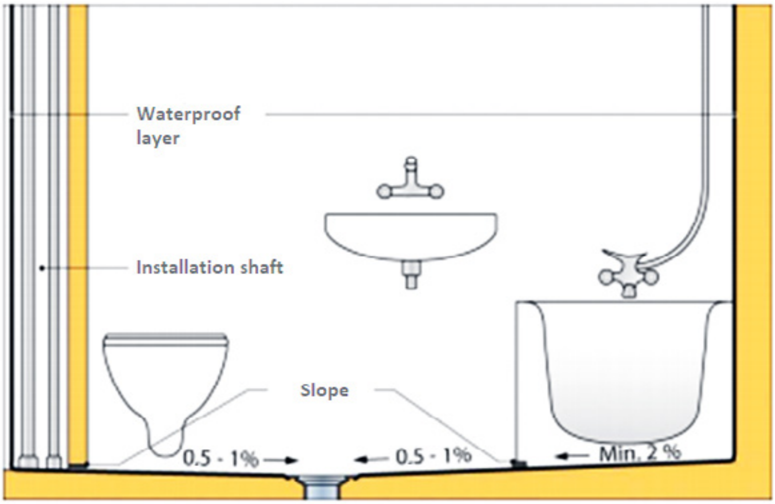

Fig. 3.49. Bathroom installations (SBI 252 Vådrum).

Fig. 3.50. Rewarding drop.

It is important that all joints are completely tight to water, not least when the substrate in a wet room is made of wood. At drains there must be stricter supervision regarding the design; it is important that an approved membrane is used for the purpose.

At drains, there will be a high water impact; drains and membranes that are approved for the purpose must be used (Fig. 3.51).

Remember to insulate the pipes where there is a risk of condensation because condensation will cause the wood element to become damp, and this wetting will cause decomposition of the wood element (Fig. 3.52).

Penetrations become leaky and wood is discarded if these installations are hidden. It often takes a long time before these leaks are discovered, and this can have major consequences for the life of the building (Fig. 3.53).

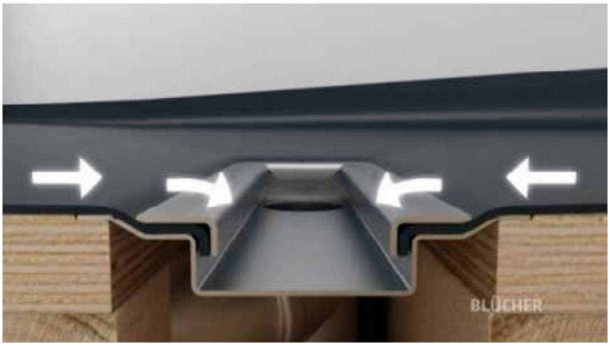

Fig. 3.51. Drains and membranes (Blucher, 2020).

Fig. 3.52. Pipes (Byggeskadefonden, 2020).

Fig. 3.53. Leaks (Byggeskadefonden, 2020).

Bathrooms made of heavy materials such as concrete are preferable (Fig. 3.54). Concrete has the property of being very dimensionally stable at indoor temperature and form a good base for waterproofing a wet room. Concrete does not decompose in the event of leaks, such as penetrations or wet room protection. In bathrooms built of wood, there will be a risk that leaks will lead to mould and rot in constructions.

Fig. 3.54. Finished bathroom made of concrete (Byggeskadefonden, 2020).

3.6.5. Penetrations in the outer walls

Penetrations in the outer walls of wooden elements are important to be made tight so that no convection occurs. If convection occurs, high humidity can pass through the outer wall and release moisture to the wood and thereby there may be a risk of mould or fungal infestation with consequent degradation (Fig. 3.55).

Because convection does not occur at penetrations, sealing cuffs can be used; they will be able to close tightly to the pipe and the wooden wall so that no convection occurs (Fig. 3.56).

In this section, we have a look at a small part of the Building Service in a building where the primary structures are built of wood.

The fact that the buildings are primarily built of wood can provide new and different construction methods.

There must be a lot of focus on the wooden structures not being exposed to moisture, for example from condensation, building moisture, leaky installations, as this can have a great impact on the life of the building.

Wood is a building material we have built with for many years and will continue to build with. Wood as a building material must be treated with care, but this applies also to other building materials.

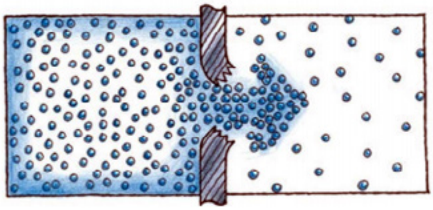

Fig. 3.55. Convection (Isover, 2020).

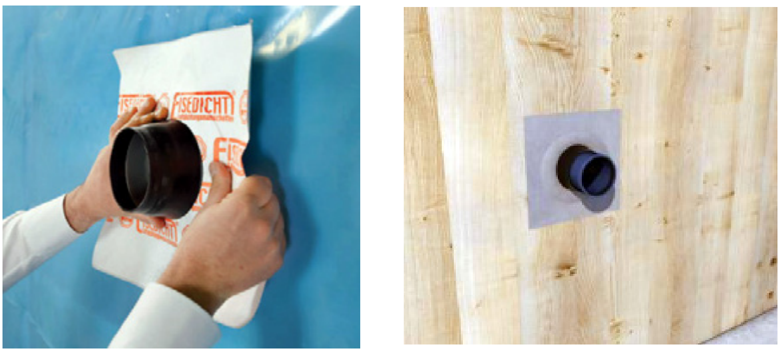

Fig. 3.56. Sealing cuffs (Rothoblaas, 2019).

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